Design and Performance Criteria for Settling Tanks for the Removal of Physical-Chemical Flocs

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DESIGN AND PERFORMANCE CRITERIA FOR SETTLING TANKS FOR THE REMOVAL OF PHYSICAL-CHEMICAL FLOCS

by

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ABSTRACT

The objective of this research was to study, both on a laboratory and full-scale plant basis, the settling behaviour of physical-chemical suspensions and to produce design and performance criteria for mixing-coagulation and settling tanks in wastewater treatment plants.

A brief literature review confirmed the belief that relatively little work on this topic has been carried out, although some pertinent background material is available. Approximately 50 long and short tube settling tests were carried out at the university laboratories on Humber Sewage Treatment Plant raw wastewater, without and with chemical addition (alum, ferric chloride, lime, polymers). Plant studies at Sarnia over a period of eight months and at Windsor for one month only were carried out. Background data on each plant during periods with and without chemical treatment were analyzed statistically and are presented graphically. Long tube settling tests were carried out at the plants for comparison of plant to test results. The results are presented in relation to type and dosage of chemical used, effluent suspended solids and BOD, overflow rate and detention time.

Results of the laboratory tests show that all three coagulants (alum, ferric chloride, lime) used in this study

increased settling rates of solids, but to varying degrees. Lime produced fastest settling flocs, ferric chloride intermediate and alum slowest rates. Addition of polymer and recycling of sludge further increased settling rate. For the Sarnia clarifiers a scale-up factor of 2.0 was determined, meaning that laboratory settling rates (or overflow rates) must be halved for plant design to allow for the effects of turbulence, etc. in the clarifier. Variations in plant overflow rate between 300 to 600 gpd/ft^2 (15 to 30 m^3/m^2/day) effected effluent quality only slightly. Laboratory data indicate that this may also hold true at higher overflow rates, but this is not confirmed at this time through plant tests. Work will be continuing in 1973/74 on this study.

It should be pointed out here that both the Sarnia and Windsor plants have primary treatment only.

RESUME

La présente recherche avait pour but d'étudier tant en laboratoire qu'en usine,le comportement à la décantation des suspensions physico-chimiques et de fournir des critères de conception et de fonctionnement pour la coagulation et les decanteurs employés dans les usines de traitement des eaux usées.

Une brève consultation des ouvrages parus sur la question a confirmé l'impression qu'il s'agissait la d'un domaine relativementé peu exploré. Néanmoins, il existe une certaine documentation de base. Une cinquantaine d'essais de coagulation en courts et longs tubes, avec et sans coagulants chimiques, (alun, chlorure ferrique, chaux, polymères) ont été effectués dans les laboratoires universitaires avec des eaux usées brutes de l'usine de traitement d'Humber. On a aussi fait des études en usine, d'une durée de plus de huit mois à Sarnia et d'un mois seulement à Windsor. Les données de base obtenues dans chaque usine pour les périodes de traitement avec et sans agent chimiques ont été analysés statistiquement et mises en graphique. Des essais de décantation en longs tubes ont été faits en usine afin de pouvoir comparer leurs résultats à ceux qui avaient été obtenus en laboratoire. Les résultats sont présentés en rapport avec le type et le dosage des agents chimiques employés, les matières en suspension de l'effluent et DBO, la vitesse de surverse et le temps de rétention.

Les résultats des essais en laboratoire montrent que les trois coagulants employés dans la présente étude (alun, chlorure ferrique, chaux) ont permis k'accroître la vitesse de décantation des solides, mais à differents degrés. C'est la chaux qui a donné la précipitation la plus rapide, suivie du chlorure ferrique, et enfin de l'alun. L'addition de polymères et le recyclage des boues ont permis d'accélérer encore davantage le taux de précipitation. Un facteur d'agrandissement à l'échelle de 2.0 a été établi pour les clarificateurs de Sarnia, ce qui signifie que les vitesses de décantation (ou vitesses de surverse) obtenues en laboratoire doivent être réduites de moitié de façon a tenir compte dans la conception de l'usine des effets de la turbulence, etc. dans le clarificateur. Des variations de vitesse de surverse en usine de l'ordre de 300 a 600 gallon par jour/pi^2 (de 15 a 30 m^3/m^{2}jour) n'ont eu qu'un faible effet sur la qualité de l'eau de l'effluent traité. Il semble, selon les resultats obtenus en laboratoire, que cela peut s'appliquer également aux plus grandes vitesses de surverse, mais cela n'a pas encore été confirmé par essais en usine. Les travaux de recherche se poursuivront en 1973/1974.

Il faudrait mentionner le fait que les usines de Sarnia et de Windsor ne sont équipées que pour le traitement primaire.

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1. INTRODUCTION

The recent emphasis on phosphorus removal has brought about an increased emphasis on chemical treatment of wastewater. Coagulants/precipitants may be added in primary, secondary or tertiary tanks for the principal purpose of phosphorus removal, with concurrent increased removal of solids and organic matter. This will result in settling slurries of a different nature and amount with different settling behaviours than present physical or physical-biological slurries.

Much work has been carried out recently in Ontario and other places on treatability studies for phosphorus removal using various coagulants. Very little work has been done on the settleability of these physical-chemical sludges. Many primary settling tanks are now overloaded or performing unsatisfactorily for a variety of reasons. The need to institute phosphorus removal may allow an opportunity to solve both problems, phosphorus removal as well as physical removal of solids and organics within one tank. However, considerable basic information on settling behaviour of these slurries as well as studies on existing plants will be required before the necessary design and operating criteria can be established.

In this study it was realized right from the

outset that it is imperative that laboratory settling behaviour must be confirmed through plant studies. Therefore after extensive work on long tube settling tests at the university laboratories work was carried out at the Sarnia and Windsor Water Pollution Control Centres. The findings are preliminary only at this time, but show promise for success. Funds are provided for a continuation of the work.

2. EXTENT OF STUDY

The following work was carried out during the period July 1972 to March 1973.

Preliminary Work

(a) Brief literature survey

(b) Detailed research programme

(c) Search for treatment plants where field work can be carried out

Items (b) and (c) were the subjects of Progress Report No. 1 dated September 19, 1972, and have been summarized as follows:

The research programme was worked out in two parts: (i) to study settling characteristics of physical-chemical flocs in settling columns, and (ii) to compare the settling column results with plant performance. Laboratory experiments were conducted initially on raw wastewater brought from the Humber Sewage Treatment Plant. Unfortunately, it was not possible to check laboratory results against plant performance since this plant (or any other plant in Toronto) was not practising chemical treatment. For plant performance studies, it was desirable to find a plant which fulfilled the following requirements:

- practising chemical treatment
- had reasonable laboratory facilities
- ability to vary overflow rate to clarifiers
- within reasonable travelling distance

With the help of Ontario Ministry of Environment, the plants at Windsor and Sarnia were selected for further studies. The Windsor plant has round, centerfeed tanks and the Sarnia plant has rectangular tanks. It is possible to change overflow rate to clarifiers at the Sarnia plant only, by cutting out one, two or three of the four existing clarifiers.

Windsor plant discontinued chemical treatment after concluding the experiments on the choice of chemicals. Only one set of experiments was carried out at Windsor by us. Most of the work was, therefore, performed at Sarnia.

Laboratory Studies

Laboratory studies were conducted at the Humber Sewage Treatment Plant on raw wastewater, with and without chemical addition. About 50 long and short tube settling tests were carried out, with additional jar testing, thickening and specific resistance tests on fewer samples.

Field Studies

(a) A performance evaluation of the Sarnia Wastewater Treatment Plant (with and without chemical treatment) was made. This was done by obtaining plant data for one year prior to initiation of chemical treatment (September 1971 - September 1972) by plant personnel, the Dow Study and Ontario Ministry of Environment study.

(b) Column settling tests were made at Sarnia and Windsor. Six one-week studies were carried out at Sarnia and one one-week study at Windsor.

3. SUMMARY AND PRELIMINARY CONCLUSIONS

(1) There is little information in the recent literature on the settleability of physical-chemical flocs, which would help to formulate design and operating criteria.

(2) Work done on the Sarnia Wastewater Treatment plant shows that plant performance on suspended solids (ss) removal can be predicted with reasonable accuracy from settling column tests.

(3) Laboratory settling column tests showed that all three chemicals tested (alum, ferric chloride and lime) were effective in increasing settling rate of flocs. Lime produced fastest rates, ferric chloride intermediate and alum slowest rates. Addition of polymer in combination with inorganic chemicals further increased settling rates. Dosages for optimum settling were considerably higher than for optimum phosphate precipitation.

(4) Most of the settleable suspended solids settled in the first 20 minutes in settling column (probably in 40 minutes in plant clarifier).

(5) Performance evaluation of the Sarnia Wastewater Treatment plant showed the following:
- the influent is primarily domestic, rather weak sewage
- the primary plant prior to chemical addition produced a reasonably good effluent (63 mg/l BOD, 38 mg/l SS)
- chemical addition of ferric chloride (10 - 20 mg/l) and alum (80 - 90 mg/l) reduced effluent total phosphorus to 0.9 and 1.5 mg/l respectively.

- SS and BOD removals were increased by the addition of ferric chloride and alum.
- additional application of polymer (Purifloc A-23) at dosages of 0.3 - 0.5 mg/l further reduced SS, but did not further reduce BOD or phosphorus.
- for optimum removal of phosphorus, SS and BOD ferric chloride at a dosage of 17 mg/l together with 0.3 mg/l Purifloc A-23 should be used. Effluent quality will be about 0.8 mg/l P, 31 mg/l BOD and 12 mg/l SS.
- there appears to be no strong influence of overflow rate on SS in the effluent within the range of 300 to 800 gpd/ft^2 (14.7 to 39.1 $M^3/M^2/$ day). There are insufficient plant data to predict the influence at higher overflow rates.

4. LITERATURE REVIEW

A literature search produced very little information on settling studies of physical-chemical flocs, with the exception of some work done in part prior to the award of this contract. See Qazi (October, 1972). It may be that, concurrent to the widespread experiments on phosphorus removal work has been going on which has not yet been published.

Work so far under this contract indicates that investigations must be broadened to include such studies as floc formation, floc breakup, and hydraulic behaviour of the settling tank. Therefore the breadth of literature to be reviewed is widened. However, it is not necessary to prepare an exhaustive literature search on such topics as coagulation-flocculating, mixing, hydraulic model studies, etc. Therefore the literature review has been limited to recent and most pertinent articles.

State-of-the-art reviews of coagulation and flocculation were published by Jorden (1971) and the American Water Works Association research committee (1971). This latter concentrated on the chemistry of coagulation and includes 88 references.

The physical and chemical factors affecting coagulation-flocculation of water were reviewed by Moffett (1968).

O'Melia and Stumm (1967) studied the coagulation and restabilization of silica dispersion by iron. The coagulation process was studied as a function of pH, applied metal ion concentration, and surface area of the dispersed phase.

Carr (1967) reviewed the nature, types, and action of polyelectrolytes used in the treatment of water or wastewaters.

Walles (1968) discussed the influence of polymer molecular weight on the rate of flocculation.

Stumm and O'Melia (1968) reviewed basic principles of coagulation-flocculation with polymers and with hydrolysed metal ions. Chemical factors effective in destabilization of colloids were emphasized. It was concluded that colloid stability is affected by colloid-solvent, coagulant-solvent, and colloid-coagulant interactions. Coagulation process must be considered as one of several interdependent components of water treatment facility. It was stressed that more attention should be directed to the physical and chemical properties of floc, i.e. density, sheer strength, compressibility, and filtrability.

Busch and Stumm (1968) studied the flocculation of _aerobacter aerogenes_ and _Escherichia Coli_ with non-ionic and anionic synthetic polyelectrolytes and demonstrated that negatively charged microorganisms can be aggregated by polymers of equal sign and that reduction of surface potential

is not a prerequisite for flocculation. Agglomeration apparently results from specific adsorption of polymer segments and from bridging of polymers between the cells.

Jones (1966) investigated the effect of cationic polymers on coagulation of raw wastewater and activated sludge and the dewatering characteristics of digested sludge. The overall efficiency of the three polymers used was the same, but the polymer with the highest molecular weight produced a larger floc which settled more readily and was more resistant to breakup.

Harris et al (1966) extended the theory of orthokinetic flocculation to systems approximating those encountered in water treatment plant flocculators. The theory incorporated parameters representing the floc size distribution, flocculator compartmentalization, and floc concentration, as well as the input energy and retention period.

In studies of the physical nature of flocculation process, the mechanics of aggregation through interparticle collision generally has been emphasized more than the role of floc breakup. It is, however, the balance of the opposing processes of aggregation and breakup that determines flocculator performance.

Parker et al (1972) attempted to develop an understanding of basic floc breakup mechanisms. A theory was derived for breakup of the complex activated sludge floc and applied to inorganic chemical flocs as well.

From bench-scale studies, Argaman and Daufman (1970) investigated energy relationships during flocculation. They derived a performance equation incorporating such parameters as residence time, number of compartments, stirrer characteristics, and energy requirements.

Black and Vilaret (1969) studied the effect of particle size on turbidity removal using kaolinite clay and monodispersed polystyrene latex particles that were coagulated with alum, calcium chloride, and cationic and nonionic polymers. From the results it was concluded that particle size has qualitative effect on required dosages of coagulant.

Hudson (1965) derived a mathematical relation describing the kinetics of flocculation. The relation indicates that the entrapment of suspended matter by floc is influenced by the volume of floc produced rather by the size or appearance of floc particles. Jar tests indicated that floc can be made more compact with extended agitation without impairing its settling characteristics.

Vold (1963) developed a computer simulation model for floc formation by random conjunction of primary particles. The results reported by him may be used to estimate a size-density relationship for flocs formed in water treatment practice. The theoretical model indicates that the buoyant density (floc density minus density of mother liquor) of floc decreases with increasing size. However, because of its idealized nature, this model should be regarded as providing

only an approximation for floc size-density relationships.

From laboratory measurements Lagvankar and Gemmell (1968), reported that a size-density variation does exist. The density decreases with the increase in floc size. It was observed that the intensity of agitation provided during flocculation does not affect floc density relationship. It does, however, alter the floc size-frequency distribution and thereby the density characteristics of the suspension. From limited observation it was claimed that coagulant aid (Purifloc C-32) used in small concentrations (up to 0.4 mg/l) along with ferric sulfate, does not alter floc densities, size-for-size.

The importance of flocculation in the removal of micron-sized mineral and biological particles led to the study of a defined velocity gradient flocculator by Van Duuren (1968). The experimental equipment consisted of coaxial cylinder, Couett device. Floc flow patterns were observed in flocculation tests with quartzite particles and alum.

Tekippe and Ham (1971) experimentally evaluated the effects of different velocity-gradient paths on the removal of turbidity. It was claimed that the intensity of mixing, time at which such mixing is begun, and the period of its duration play a vital role in the turbidity of the final water product. The most important conclusion derived from this work was that, for constant Gt and settling periods

commonly used in practice ($\geq$ 30 minutes), the tappered velocity gradient path resulted in the greatest turbidity removals. For very short settling periods (5 minutes), however, a step-up velocity gradient path was found to give turbidity removals that were at least equal to the tappered path.

The importance of rapid mix in conjunction with chemical treatment was studied by Vrale and Jorden (1971). It was concluded that tubular reactor is better than a back-mix type, and the root-mean square velocity gradient was inadequate for characterization of rapid mix efficiency.

Hudson (1972) studied the effects of temperature, turbidity and salinity on sedimentation operation. It is claimed that any alteration that changes the density of water entering the sedimentation tanks can cause incoming water to bypass its normal route. This short-circuiting reduces the detention time in clarifier and consequently reduces sedimentation. From the analysis of settling energy of flocs and impairing influences in clarifier it was emphasized that changes in water quality can cause severe upset in clarifiers. The stabilizing forces in conventional basins are not adequate to control density currents. The combination of surface weirs or launders and slurry recirculation can effectively control density currents, when the flocs formed are sufficiently dense.

Fitz, L.W. (1969) investigated the use of liquid tracers as a means of obtaining information concerning the behaviour of solids in vessel. This specifically included setting a mixed model composed of back mix flow regions, dispersed plug flow regions, dead water regions, etc., and used it to compare the actual and predicted distribution functions for the experimental vessel.

Tekippe and Cleasby (1968) dealt with the problem of obtaining reproducible results from identical experiments using dye dispersion curves to evaluate the hydraulic efficiency of settling tanks. Several techniques for defining and improving reproducibility of such experiments were given. These improved techniques were used to test changes in hydraulic performance resulting from changes in the geometric design of the model.

Wallace (1967) concluded from the results of tracer studies in a sedimention tank that the "ideal basin" concept was of little value in the analysis and design of sedimentation tanks, except in special cases. He recommended that the analysis should be based on settling characteristics of the suspension, estimated or determined experimentally and the hydraulic characteristics of the tank. The techniques used to determine the hydraulic characteristics of a tank were described.

Thirumurthi (1969) developed from tracer and sedimentation studies a design formula for real sedimentation

tanks. Two selected parameters were shown to be reproducible and representative enough to be used as design criteria of sedimentation systems. The deviation of real systems from ideality was taken into account.

Takamatsu and Naito (1967) studied the effects of flow conditions on the efficiency of sedimentation vessel. Two simple mathematical models were developed to describe fluid motion in sedimentation tanks under conditions of circulating flow and turbulence, and a formula expressing particle settling efficiency was described in each case. Satisfactory agreement was obtained between theoretical and observed values.

Aitken (1967) described the historic development of sedimentation tanks from the simplest horizontal-flow and radial-flow tanks to the more recent upward-flow sludge blanket type. The importance of Reynolds number was stressed.

Geinopolos et al (1966) discussed the suspension-settling characteristics and the hydraulics of the settling basin as key factors in the clarification of water and waste-water.

Brown and LaMotta (1971) studied the behaviour of flocculent suspensions in sludge blanket clarifiers and indicated that the same functional relationship as previously determined for discrete particles could be applied.

Pflanz (1968) studied sedimentation process in clarifier by developing solids profiles. The method consisted

of drawing samples from different depths and locations and determining the suspended solids concentrations. The efficiency of secondary sedimentation basin in relation to mixed liquor solids concentration, hydraulic loading rate, and solid surface feed (product of overflow rate and suspended solids) was also investigated.

Ridenour (1930) observed rate of settling of sewage solids at various temperature. It was reported that the rate of settling increases slightly with corresponding increase of temperature up to 30°C. Above this temperature settling rapidly decreases.

Cranstone (1965) proposed a new design of a sedimentation basin involving circular radial-flow sedimentation. To improve the hydraulic efficiency and performance of circular sedimentation tanks, a system was developed in which the usual central feed pipe was replaced by a feed channel extending around the entire periphery of the tank. Orifices in the floor of the feed channel directed the flow downward into the tank between the tank wall and a vertical skirt-baffle. The system was arranged so that the flow of liquid entered the sedimentation zone near the bottom and at the lowest possible velocity, after which the flow was gradually directed upward and inward for discharge into a ring-shaped effluent trough at the centre of the tank. Laboratory studies and field trials confirmed the improved hydraulic efficiency of this peripherally-fed tank. Higher surface loading and reduced detention times were possible without impairing the

quality of the effluent.

Hansen and Culp (1967);Culp (1968);and Culp et al (1968) reported the use of inclined small diameter tubes for removal of solids from liquid. Effects of parameters, such as tube diameter, tube length, flow rate, level of influent turbidity and polyelectrolyte dosage were studied. The second paper reviewed the use of shallow sedimentation basins or inclined tubes at low Reynolds number and low detention time and their application to the removal of phosphorus from water by alum and lime coagulation.

Hansen et al (1969) described the practical application of idealized sedimentation theory by the use of a multiplicity of shallow tubes operated in parallel and sized so that streamline flow conditions were established in each tube. These tubes allowed settleable solids separation to be achieved with detention times of only 5 to 15 minutes. Considerable performance data were given on existing tube modules in clarifiers.

A basic study of tube settler systems by Yao (1970) yielded information on design of these high-rate sedimentation systems. Overflow rate and an equation developed in this study can be used to design tube settlers.

Improvement in performance of sediment basins receiving raw wastewater and biological treatment liquor by the installation of tube settlers was studied by Slechta and Conley (1971). Overflow rates in the range of 3 gpm/sq ft (122 l/min/ sq m) to 6 gpm/sq ft (224 l/min/sq m) were found

feasible.

Stewart and Montbriand (1972) investigated the use of high rate tube clarifiers in chemically treated secondary effluent from stabilization pond. It was reported that there was no significant breakdown in treatment efficiency and suspended solids removal at overflow rate as high as 6000 gpd/sq ft. The corresponding figures without the settling tune module could be between 1000 to 1450 gpd/sq ft.

Improvement in settling tank efficiency was described by Sparham (1970) and Crockford and Sparham (1972). Based on the concept of the pebble-bed upward-flow clarifier, perforated plate or wedge wire panels were installed in a clarifier with improvements in settled effluent quality.

Reed et al (1972) developed a floating settler which, it is claimed, retains all the advantages of high rate tube clarifier but in addition provides some very significant benefits: (a) Its utilization in the aeration unit eliminates the need for separate clarifier basins and tanks;(b) Since the settled sludge leaving the module is already in the aeration compartment, the need for sludge collection and return equipment is eliminated; (c) Since module floats , it is always in the same position with respect to the general liquid surface in the tank.

5. LABORATORY STUDIES

To examine various phenomena of chemical precipitation experiments on column settling, jar test, thickening test and specific resistance tests were performed. The major part of the work was done by the use of settling columns. These have been used routinely to establish settleability of wastewater flocs without chemical addition. In this test a column of uniformly mixed dilute suspension is allowed to settle under quiescent condition in a long tube, 7 feet (2.13 m) in length, 6 inches (0.18 m) in diameter. Samples of wastewater are taken from the column at suitable time intervals from the sampling ports which are provided at one foot (0.30 m) depth intervals. Samples are then filtered to find out the concentration of suspended solids for various detention times, and at various depths of water (for more detail see Appendix A-1). From this information a 'design graph' is developed which relates suspended solids removal for given overflow rates and detention times. To convert batch settling column results to plant scale, scale-up factors are used to account for the reduced removal in continuous flow.

A settling column test is lengthy and time consuming. It requires about four hours for preparing and conducting each test. Another 15 to 20 hours are required to process the test data to a meaningful end result. End

results are somewhat dependent on interpretation of data by the individual doing the work. In total it may take 600 to 1000 man hours to perform sufficient tests on one plant to obtain reliable experimental scale-up factors. Whether they would apply at other plants depends on many factors. An alternative method to the time consuming gravimetric method could reduce the time considerably. Work presently under way at McMaster University (Dr. K. L. Murphy) on the use of lasers may be tried within a year or so. On plant-scale measurements a suspended solids monitor manufactured by Partech Limited was tried recently and showed promise.

Grab samples were brought from the Humber Sewage Treatment plant. Chemicals were mixed in the laboratory and tests were performed with settling columns. Forty-seven settling column tests (29 with inorganic chemicals only; 9 with chemical addition in combination with polymers and 9 with no chemical addition as 'control') were performed. Alum, ferric chloride and lime were used in varying dosages to compare the performance of these chemicals at different levels of concentration. Effect of recycling of settled sludge, and use of polymer were studied as means to improve settling characteristics of chemical flocs. Unfortunately this plant (or any other plant in Toronto) does not practice chemical treatment and, therefore, data developed in the laboratory could not be related to plant-scale operation.

The raw wastewater from this plant was combined (industrial and domestic) and strong in nature having

average total solids of 1225 mg/l (suspended: 435 mg/l and dissolved: 790 mg/l), 5 day BOD around 300 mg/l, alkalinity 215 mg/l along with significant amounts of fats and blood. The average total phosphates (unfiltered) content was 29.0 mg/l as PO_4.

Summary of Data

Table 1 (Alum), Table 2 (Ferric Chloride) and Table 3 (lime) summarize the results of the column settling tests. The tables have been set up to show the effect of type of chemical used, dosage of chemical and overflow rate (developed on batch test) on the settling of flocs. Table 4 presents the effect of recyling of settled sludge. Table 5 presents the effect of addition of polymer on settling.

TABLE 1

Results of Settling Column Tests with Alum

(Based on 15 minutes detention time)

Suspended Solids Remaining in Supernatant mg/l

Alum Dosage mg/l →		Control	140	200	Control	200	250	Control	250	Control	250
Initial Conc. of SS mg/l →		316	402*	422*	443	553*	494*	402	427*	414	545*
Overflow Rate											
gpd/ft^2	$m^3/m^2/day$										
900	44	190	241 (+51)**	173 (-17)**	177	21 (-156)**	8 (-169)**	-	2	-	0
1800	88	198	253 (+55)	211 (+13)	191	21 (-170)	8 (-183)	-	2	-	0
2700	132	206	269 (+63)	224 (+18)	208		8 (-200)	-	2	-	0
3600	176	213	281 (+68)	237 (+24)	221	Max. O.F.R. 1800 gpd/ft^2 88 $m^3/m^2/day$	Max. O.F.R. 2520 gpd/ft^2 123 $m^3/m^2/day$		Max. O.F.R. 1530 gpd/ft^2 75 $m^3/m^2/day$		Max. O.F.R. 2700 gpd/ft^2 132 $m^3/m^2/day$

* Concentration after chemical addition

** Figures in parentheses are NET reduction in SS due to chemical additions; -ve sign indicates reduction, +ve indicates increase in SS in supernatant

TABLE 2

Results of Settling Column Tests with Ferric Chloride

(Based on 15 minutes detentime time)
Suspended Solids Remaining in Supernatant mg/l

Ferric Chloride mg/l (Fe)		Control	17	Control	17	34	Control	43
Initial Conc. of SS mg/l		448	488*	600	655*	667*	402	534*
Overflow Rate gpd/ft^2	m^3/m^2/day							
900	44	275	273 (-2)**	203	131 (-72)**	100 (-103)**		32
1800	88	311	307 (-4)	239	131 (-108)	100 (-139)		32
2700	132	336	320 (-16)	274	Max. O.F.R. 1800 gpd/ft^2 88 m^3/m^2/day	Max. O.F.R. 1800 gpd/ft^2 88 m^3/m^2/day		Max. O.F.R. 1800 gpd/ft^2 88 m^3/m^2/day
3600	176	349	327 (-22)	286				

* Concentration after chemical addition
** Figures in parentheses are NET reduction in Suspended solids due to chemical addition

continued ......

TABLE 2 (continued)

Results of Settling Column Tests with Ferric Chloride

(Based on 15 minutes detention time)
Suspended Solids Remaining in Supernatant mg/l

Ferric Chloride mg/l (Fe)		Control	52	52	Control	52	52	Control	52
Initial Conc. of SS mg/l		400	513*	530*	507	594*	594*	414	624*
Overflow Rate gpd/ft^2	$m^3/m^2/day$								
900	44	224	51 (-173)**	48 (-176)**	152	6 (-146)**	6 (-146)**		0
1800	88	264	51 (-213)	48 (-216)	178	6 (-172)	6 (-172)		0
2700	132	288	Max. O.F.R. 1620 gpd/ft^2 79 $m^3/m^2/day$	Max. O.F.R. 1980 gpd/ft^2 97 $m^3/m^2/day$	203	Max. O.F.R. 1530 gpd/ft^2 75 $m^3/m^2/day$	Max. O.F.R. 1800 gpd/ft^2 88 $m^3/m^2/day$		Max. O.F.R. 2025 gpd/ft^2 99 $m^3/m^2/day$
3600	176								

* Concentration after chemical addition
** Figures in parentheses are NET reduction in Suspended solids due to chemical addition

TABLE 3

Results of Settling Column Tests with Lime

(Based on 15 minutes detention time)

Suspended Solids Remaining in Supernatant mg/l

Lime Dosage mg/l, $Ca(OH)_2$		Control	150	200	Control	175	Control	200	200
Initial Conc. of SS mg/l		400	608*	609*	453	625*	507	730*	730*
Overflow Rate gpd/ft^2	m^3/m^2/day								
900	44	127	54 (-73)**		262	162 (-100)**	152		
1800	88	155	78 (-77)	122 (-33)	286	181 (-105)	183		
2700	132	199	96 (-103)	127 (-72)	303	184 (-199)	203	52 (-151)	44 (-159)
3600	176	219	103 (-116)	134 (-85)	317	184 (-133)	218	52 (-166)	44 (-174)
4500	220	239	110 (-129)	134 (-105)		188	229	Max. O.F.R. 3600 gpd/ft^2 176 m^3/m^2/day	Max. O.F.R. 3870 gpd/ft^2 185 m^3/m^2/day

* Concentration after chemical addition

** Figures in parentheses are NET reduction in suspended solids due to chemical addition

continued........

TABLE 3 (continued)

Results of Settling Column Tests with Lime

(Based on 15 minutes detention time)
Suspended Solids Remaining in Supernatant mg/l

Lime Dosage mg/l, $Ca(OH)_2$		Control	200	250	Control	300	Control	300	Control	300
Initial Conc. of SS mg/l		378	632*	642*	443	856*	402	670*	414	873*
Overflow Rate gpd.ft^2	m^3/m^2/day									
900	44	287	177 (-110)**		177			6		80
1800	88	314	202 (-112)		191			6		80
2700	132	325	221 (-104)	72 (-253)	208	0 (-208)		6		80
3600	176	333	226 (-107)	72 (-261)	221	0 (-221)		6		80
4500	220	340	234 (-106)	72 (-268)	235	0 (-235)		Max. O.F.R. 3600 gpd/ft^2 176 m^3/m^2/day		80

* Concentration after chemical addition
** Figures in parentheses are NET reduction in suspended solids due to chemical addition

TABLE 4

Effect of Recycling of Chemical Flocs

(Based on 15 minutes detention time)

Suspended Solids Remaining mg/l

Chemical		Lime as $Ca(OH)_2$						Ferric Chloride as Fe	
Dosage →		150 mg/l		175 mg/l		200 mg/l		17 mg/l	
Overflow Rate		without Recycling*	with Recycling*	without Recycling*	with Recycling*	without Recycling**	with Recycling**	without Recycling*	with Recycling*
gpd/ft^2	$m^3/m^2/day$								
900	44	54		162				273	194 (-79)
1800	88	78		181		122		307	241 (-66)
2700	132	96	53 (-43)	184	128 (-56)	127	112 (-15)	320	272 (-48)
3600	176	103	53 (-50)	186	128 (-58)	134	112 (-22)	327	285 (-42)
4500	220	110	53 (-57)	188		134	112 (-22)	332	292 (-40)

* 50% of settled sludge recycled
** 100% settled sludge recycled

Figures in parentheses are NET reduction in suspended solids due to recycling

TABLE 5

Effect of Polymer* Addition @ 1.0 mg/l

(Based on 5 minutes detention time)

Coagulants	Alum			Ferric Chloride, Fe			Lime		
	W/O	With Polymer		W/O	With Polymer		W/O	With Polymer	
Dosage mg/l	250	250	150	52	52	26	300	300	150
Suspended Solids Remaining mg/l	36	12	34	84	10	28	74	36	29
Max. Overflow Rate gpd/ft^2 (m^3/m^2/day)	2700 (132)	9000 (440)	9000 (440)	2025 (99)	9000 (440)	9000 (440)	5040 (246)	12000 (586)	12000 (586)

* Percol 725 (anionic)

Discussion of Laboratory Results

All three chemicals used (alum, ferric chloride, lime) were effective for phosphorus removal. Soluble phosphates were reduced to about 1 mg/l PO_4 with dosages of about 100 mg/l of lime and alum, and 34 mg/l of ferric chloride as Fe. However for optimum settling, as measured by total phosphorus and suspended solids removal, higher dosages were required (for alum and lime 250 mg/l, for ferric chloride 43 mg/l). The operating pH for alum and iron flocs was determined at 6.0 - 6.5 and for lime flocs 10 or above.

Tables 1, 2 and 3 show that the use of all three chemicals (alum, ferric chloride and lime) markedly improved the quality of 'effluent' as measured by suspended solids remaining. Addition of chemicals produced large (1/10" - 1/8" or 2.5 mm - 3.0 mm) but fluffy looking flocs, which generally settled in phase (an interface developed between high turbide wastewater and clear supernatant). Interface settling rate was highest with lime addition (maximum 0.6 ft/min or 8.3 cm/min) whereas with alum and ferric chloride maximum settling rate was in the order of 0.25 ft/min (7.6 cm/min).

During the experiments, it was noticed that the flocs developed under the relatively ideal conditions of a jar test were small and compact in appearance. In the settling column test, where the mixture was flocculated by recycling through a pump, the flocs were broken by local intense turbulence in the pump. The floc fragments, however, rebuilt into big fluffy flocs when the pump was stopped. This floc formation settled at a slower rate than the jar test flocs.

The damaging effect of long and intense turbulence was serious for alum flocs, but relatively minor for lime and ferric flocs.

With chemical addition the major fraction of suspended solids (80% or more) settled within the first 15 minutes of detention time. This detention was used for comparing settling behaviour of chemical to physical flocs. The suspended solids remaining in the control tests (without chemical addition) increases with increasing overflow rate, whereas there is little such variation in the tests with chemical addition.

Table 4 shows that recycling has beneficial effect on clarification of wastewater and that the effect of recycling is more significant at lower dosages of chemicals than at higher dosages, suspended solids remaining reduced by an amount varying from 15 to 57 mg/l in the case of lime and 40 to 79 mg/l in the case of ferric chloride. Recycling however did not improve phosphate removal. The improvement by recycling could, probably, be due to the sweeping action of flocs rather than any beneficial effect on coagulation process. Data not presented also indicate that the recycling rate should be such as to deep the concentration of suspended solids somewhere between 600 to 700 mg/l. Above 800 mg/l clarification may start deteriorating.

Table 5 shows that suspended solids remaining are lower when using 1.0 mg/l of polymer (Percol 725) together with inorganic chemicals. It also produces faster settling thus allowing increased overflow rates, as calculated from settling column data. There is an indication that the use of polymer may allow reduction in dosages of inorganic chemical with-

out adversely affecting suspended solids and phosphate removal efficiencies. For this particular wastewater polymer dosages of 0.5 mg/l and lower did not produce significant improvement in settling. Preliminary cost analysis indicates that polymer at a dosage of 1.0 mg/l together with inorganic chemicals will be cheaper than inorganic chemical alone.

6. FIELD STUDIES

(a) Performance Evaluation of the Sarnia Wastewater Treatment Plant

General

The Sarnia Wastewater Treatment plant is a primary treatment plant treating on the average 6.5 MGD (3×10^4 cu m/day). The treatment consists of screening, preaeration, settling, chlorination, sludge digestion and lagooning. The plant has experimented with chemical treatment (ferric chloride, alum, polymers) since September, 1971. For a shorter period of time Dow Chemical Company was involved, then the Research Division of the Ontario Ministry of the Environment. The City of Sarnia will continue chemical treatment and the more extensive laboratory analyses involved on its own. The conditions experienced during the time covered in this report are shown in Table 6. Plant data prior to September 1, 1971 and after July, 1972 were obtained from plant records, data from September, 1971 to July, 1972 were supplied by Messrs. Rupke and Gray of the Research Branch of the Ontario Ministry of the Environment. No detailed analysis has been made by them.

Data Analysis and Discussion

The following parameters were measured: flowrate,

TABLE 6

Record of Work at Sarnia Wastewater Treatment Plant

Date	Organization	Chemical Added Fe mg/l	A23 mg/l	Alum mg/l	No. of Clarifiers in use
Sept.1,1970-Aug.31,1971	City of Sarnia	-	-	-	4
Sept.1,1971-Sept.26,1971	Dow Chem.Co. & City of Sarnia	-	-	-	3
Sept.29,1971-Oct.16,1971	"	15	0.3	-	3
Oct.17,1971-Nov.2,1971	"	15	0.5	-	3
Nov.3,1971-Nov.8,1971	"	20	0.5	-	3
Nov.9,1971-Nov.20,1971	"	10	0.3	-	3
Nov.21,1971-Dec.1,1971	"	15	-	-	3
Dec.2,1971-Dec.13,1971	"	20	-	-	3
Dec.18,1971-Dec.26,1971	"	20	0.3	-	3
Jan.4,1972-Jan.16,1972	Ont. Min. of Env. & City of Sarnia	17	0.3	-	3
Jan.18,1972-Feb.10,1972	"	17	-	-	2
Feb.13,1972-Mar.5,1972	"	17	-	-	2
Mar.6,1972-Mar.8,1972	"	17	-	-	1
Mar.9,1972-Mar.23,1972	"	17	-	-	2
Mar.26-1972-Apr.18,1972	"	17	0.23	-	2
Apr.20,1972-May 23,1972	"	10	-	-	3
May 24,1972-July 4,1972	"	17	-	-	2
July 9,1972-Aug.1,1972	City of Sarnia	17	-	-	4
Aug.10,1972-Aug.24,1972	"	-	-	80	4
Aug.25,1972-Sept.12,1972	"	-	0.3	80	4
Sept.13,1972-Oct.2,1972	"	-	0.3	90	4
Oct.3,1972-Oct.10,1972	"	-	0.4	80	4
Oct.11,1972-Oct.22,1972	"	-	0.5	80	4
Oct.23,1972-Nov.6,1972	"	-	0.3	90	4
Nov.7,1972-Nov.18,1972	"	-	-	80	4
Nov.19,1972-Dec.18,1972	"	-	-	-	4
Dec.19,1972-Dec.27,1972	"	17	-	-	4
Dec.28,1972-Dec.31,1972	"	12	-	-	4

suspended solids, BOD, phosphorus (total and soluble) in influent and effluent. Measurements were made on daily composite samples since September 1971, prior to that on a less frequent basis. Phosphorus measurements were started in September 1971.

All data were statistically analysed. For sample size greater than 50 a normal distribution was assumed, probabilities of occurrence calculated and plotted. For sample size less than 50 a ranking method was used first, probabilities calculated and plotted. Table 7 shows the sizes of samples used for various statistical analyses.

Daily flowrates are shown in Figure 1. The flow is quite stable, with an average of 6.35 MGD. Overflow rates were calculated using flowrate and number of clarifiers used. This is shown on Figure 2. Overflow rate varied widely from 325 to 2090 gpd/ft^2 (16 - 102 m^3/m^2/day). This fluctuation is caused mainly by the use of different numbers of clarifiers (1 to 4). When all four clarifiers are used the average overflow rate was only 390 gpd/ sq ft (19 cu m/ sq m/day).

Characteristics of influent wastewater are summarized in Table 8. The wastewater is mostly of domestic origin.

TABLE 7 Sizes of Samples Used in Statistical Analyses

Parameters		INFLUENT	EFFLUENT													
			No Chemical Addition				$FeCl_3$ Addition				$FeCl_3$ + Polymer (DOW A-23) Addition				ALUM ADDITION	ALUM + POLYMER (DOW A23) ADDITION
			TOTAL	O.R. = 300~400	O.R. = 401~500	O.R. = 501~600	TOTAL	O.R. < 600	O.R. = 600~800	O.R. > 800	TOTAL	O.R. < 600	O.R. = 600~800	O.R. > 800		
FLOW RATE		654	-	-	-	-	-	-	-	-	-	-	-	-	-	-
OVER FLOW RATE (O.R)		538	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SUSPENDED SOLID	W.W.	336	170	85	60	25	88	35	27	26	78	58	13	7	-	-
	A.T.	79	23	-	-	-	-	-	-	-	-	-	-	-	15	41
BOD_5	W.W.	309	155	-	-	-	83	-	-	-	71	-	-	-	-	-
	A.T.	55	-	-	-	-	-	-	-	-	-	-	-	-	16	39
TOTAL P.	W.W.	189	7	-	-	-	107	-	-	-	75	-	-	-	-	-
	A.T.	150	16	-	-	-	-	-	-	-	-	-	-	-	31	103

W.W. Samples collected from wet well (Sept. 1971 ~ July 1972)

A.T. Samples collected from aeration tank (Aug. 1972 ~ Dec. 1972)

TABLE 8

Influent Characteristics of Sarnia Wastewater

	Range		Average
	Max.	Min.	
Flow Rate MGD	12.00	5.25	6.35
(cu m/day)	5.45×10^4	2.38×10^4	2.88×10^4
Overflow Rate gpd/ft^2	2090	326	390
(cu m/sq m/day)	102	16	19
Suspended Solid mg/l	608	8	102
BOD mg/l	182	52	88
Total P (mg/l)	22.6	2.18	5.73

The efficiency of suspended solids removal without chemical addition is shown in Figure 3. The average effluent value was 30 - 40 mg/l with a corresponding influent value of about 100 mg/l, indicating a well working settling tank, at least under the relatively low overflow rates from 300 to 600 gpd/ft^2 (14.7 to 29.3 cu m/sq m/day).

The effect of addition of ferric chloride (and Purifloc A-23) is shown in Figure 4. Average suspended solids in effluent was reduced to 23 mg/l through addition of ferric chloride (10 - 20 mg/l, all data lumped together) and was further reduced to about 12 mg/l through further addition of a polymer, Dow Purifloc A-23 (0.23 - 0.5 mg/l). Figure 5 shows the corresponding information on BOD removal. Ferric chloride reduced the average effluent value of 63 mg/l to 34 mg/l. Practically no further improvement was brought about by the addition of polymer. Figure 6 shows the effect of

addition of ferric chloride (and polymer) on total phosphorus removal in reducing effluent total phosphorus to less than 1.0 mg/l. Further polymer addition had no effect.

The effect of addition of alum (80 - 90 mg/l) and polymer (0.3 mg/l) on suspended solids, BOD and phosphorus is shown in Figure 7, 8 and 9. In general, alum was considerably less effective than ferric chloride.

It should be noted here that samples of influent were taken from wet well after closing the valve of supernatant from the digesters till August, 1972. Later on, due to the difficuly in taking samples from wet well, it was decided to take samples from aeration tank which included supernatant from digesters. This change occurred at the time when chmical treatment with alum in plant, and the work at Sarnia started. Since samples for plant performance analyses and settling column tests were taken from the same place (aeration tank), the results of this study were not affected. For clarity, however, the samples from wet well were labelled as 'Influent' and those from aeration tank were described as 'Clarifier Influent', wherever applicable in tables and figures.

Table 9 provides a summary of information from Figures 3 to 9.

TABLE 9

Effluent Quality of Sarnia Wastewater Treatment Plant

Chemical Addition	Suspended Solids mg/l Avg.	Max.	Min.	BOD mg/l Avg.	Max.	Min.	Total Phosphorus mg/l Avg.	Max.	Min.
None	38	102	4	63	152	33	5.2	8.0	1.1
Ferric Chloride (10-20 mg/l)	23	74	9	34	80	17	0.9	5.3	0.2
Ferric Chloride plus A-23 (0.23-0.5 mg/l)	12	54	4	31	59	25	0.8	2.9	0.1
Alum (80-90 mg/l)	37	49	20	40	61	27	1.5	3.3	0.4
Alum plus A-23 (0.3-0.5 mg/l)	30	73	19	37	55	27	1.4	2.9	0.2

Table 9 indicates quite clearly that ferric chloride produced much better results than alum. Purifloc A-23 improved suspended solids removal, but did not improve BOD or phosphorus removal significantly when used together with alum or ferric chloride.

An attempt has been made in Table 10 to demonstrate the effect of varying dosages of chemical on removal of suspended solids, BOD and phosphorus. While the data may be insufficient for conclusive results the following can be said:

- 10 mg/l ferric chloride plus 0.3 mg/l A-23 for optimum suspended solids removal.
- increasing ferric chloride dosage increases BOD removal, with an optimum at 20 mg/l ferric chloride and 0.3 mg/l A-23.

- for optimum phosphorus removal use 17 mg/l ferric chloride and 0.3 mg/l A-23

A cost study has not been carried out.

TABLE 10

Effect of Dosage of Chemical on Suspended Solids, BOD and Phosphorus Levels

Chemical Added	Suspended Solids mg/l Avg.	Max.	Min.	BOD mg/l Avg.	Max.	Min.	Total Phosphorus mg/l Avg.	Max.	Min.
Ferric Chloride									
10 mg/l	25	49	10	39	48	26	1.60	3.60	0.17
15	33	62	20	39	57	29	1.18	1.68	0.77
17	32	74	9	44	80	17	1.29	5.30	0.20
20	28	62	10	37	59	29	0.74	1.13	0.34
Ferric Chloride plus A-23 (0.23-0.5 mg/l)									
10 mg/l	16	34	4	41	50	30	2.33	3.49	1.39
15	21	51	5	36	51	27	1.31	2.09	0.50
17	22	37	10	38	47	30	0.86	1.57	0.27
20	19	27	11	33	45	23	0.74	1.01	0.48
Alum									
80 mg/l	37	49	20	40	61	36	1.50	2.40	0.36
Alum plus A-23 (0.3-0.5 mg/l)									
80 mg/l	42	67	26	39	55	31	1.92	3.56	0.22
90 mg/l	29	73	19	34	45	27	1.41	2.40	0.32

An attempt was made by the Ontario Ministry of the Environment to study the effect of overflow rate on plant performance. During the period January to July 1972 the plant was operated with varying overflow rates by operating with from 1 to 4 clarifiers. During this time chemical addition

was ferric chloride only except for a short period when polymer was added additionally. Overflow rates were calculated and grouped into three classes: below 600 gpd/ft^2 (29.3 cu m/sq m/day), 600 - 800 gpd/ft^2 (29.3 - 39.1 cu m/sq m/day), above 800 gpd/ft^2 (39.1 cu m/sq m/day). Results are shown in Figures 10 to 14. Figures 10 and 11 do not indicate a strong dependence on overflow rate. Verbal reports by the staff of Ministry of Environment indicate washout when only one clarifier was used (March 6th-8th). The use of polymer reduced suspended solids at all three ranges of overflow rates. Further work is required to determine the effect of overflow rate, particularly at rates higher than 800 gpd/ft^2 (39.1 cu m/sq m/day).

(b) Settling Column Tests at Sarnia and Windsor

General

In order to assess the ability of column settling test to predict the solids removal in the plant it is necessary to carry out both column settling tests and corresponding plant evaluation at the same time. The Windsor Wastewater Treatment plant and the Sarnia Wastewater Treatment plant were selected for study. Only a one week study could be carried out at Windsor since the plant discontinued chemical treatment until the fall of 1973. Six one week studies were made in Sarnia, and this was to have been continued during 1973. In total 50 settling column tests were carried out at Sarnia and Windsor (29 with chemical addition, and 21 with no chemical addition as 'control').

The procedure was as follows: samples of sufficient size for the test were taken before and after addition of chemicals. The former sample is taken after degritting at the influent to aeration tank. The latter sample was taken from the distribution channel to the clarifier which means the mixture was flocculated for about 15 - 20 minutes in the plant. These samples were then allowed to settle in the settling column after mixing them uniformly. All necessary data were recorded. Samples of plant effluent was also taken after a time elapse of theoretical detention time of the plant and analysed for suspended solids.

Data Analysis and Presentation

All settling column data were analysed as described previously. The results are summarized in Tables 11 and 12. Table 11 compares the results obtained from settling column and plant clarifier without chemical addition. In calculating these results an overflow rate of 500 gal/day/sq ft (24.4 cu m/sq m/day) was used for each case but detention time used for settling column was one-half of plant time. The detention time for settling column was determined by working out the average of detention times required to produce effluent of the same quality as of plant.

Table 12 summarizes similar results but with chemical addition.

Figures 15 to 17 show the correlation between plant performance and settling column performance. It was necessary to compare settling column tests on wastewater without chemical addition to plant performance developed over the period September 1970 to September 1971 in section (a) Field Studies since the plant was operating with chemical addition now.

Figure 15 has been developed for plant data and shows correlation between influent and effluent suspended solids.

Figure 16 presents comparison of settling results obtained from plant and settling column test. It also shows the effect of chemical addition on the quality of effluent.

Figure 17 and 18 show the effect of overflow rate on

TABLE 11

Comparison of Performance of Settling Column and Plant Clarifier at Sarnia

WITHOUT CHEMICAL ADDITION

SS in Clarifier Influent mg/l	SS Remaining in Settling Column mg/l	SS Remaining in Plant Clarifier Effluent mg/l (estimated from Fig. 15)
Morning Grab Samples		
89	50	34
110	66	41
118	46	45
121	42	51
145	35	59
154	48	63
154	90	63
161	81	65
162	63	66
163	40	68
163	70	68
173	74	73
184	90	78
190	86	81
192	75	82
229	145	101
242	91	107
243	111	113
AVERAGE 166	72	70
Afternoon Grab Samples		
182	101	75
186	94	78
311	181	133
AVERAGE 226	125	95

Overflow Rate $\sim$ 500 gpd/ft^2 (24.4 cu m/sq m/day)
Theoretical Detention Time:
In Plant = 164 minutes
In Settling Column = 82 minutes

TABLE 12

Comparison of Performance of Settling Column and Plant Clarifier

WITH CHEMICAL ADDITION

SS in Clarifier Influent mg/l	SS Remaining in Settling Column mg/l	SS Remaining in Plant Clarifier Effluent mg/l
Morning Grab Samples		
110	10	16
118	35	32
121	24	54
145	22	20
154	24**	14**
161	36**	22**
162	36**	16**
163	38	40
163	30*	24*
173	28*	38*
184	15*	14*
190	25*	38*
192	16**	22**
229	20*	33*
242	12*	16*
243	53	26
AVERAGE 172	26	26

Afternoon Grab Samples		
	93**	84**
	98	
	110*	72*
	78*	30*
AVERAGE	95	62

* Alum Plus Polymer Addition
** Ferric Chloride Addition
Overflow Rate $\sim$ 500 gpd/ft^2 (24.4 cu m/sq m/day)
Theoretical Detention Time:
In Plant = 164 minutes
In Settling Column = 82 minutes

effluent quality in plant and settling column tests.

Figures 19 and 20 show the effect of detention time on effluent quality in settling column test at Sarnia and Windsor respectively.

Discussion of Results

Tables 11 and 12 show that the performance of a clarifier can be predicted with reasonable accuracy. To predict the performance of the Sarnia clarifiers detention times obtained by settling column test should be multiplied by a factor of 2 to obtain theoretical detention times in clarifier. As discussed above, for Table 11, plant performance without chemical addition was estimated from the past plant data (see Figure 15).

Comparison of Tables 11 and 12 shows that with chemical addition better effluent quality is obtained under given operating conditions. It is further shown that chemical treatment produces effluent which is consistent in quality. Figure 16 gives a visual picture of this.

From Table 12 it can also be seen that chemical treatment was more effective in the morning than in the afternoon. This could be due to the varying nature of wastewater. Table 11 also shows that raw wastewater in the afternoon settles poorly. Furthermore, it is also indicated that in the afternoon, plant performance was a lot better than settling column. This may be due to equalization effect of clarifier. However, plant effluent for the afternoon flow

was higher in suspended solids than that of the morning.

Figure 17 indicates that the plant effluent suspended solids concentration is not very sensitive to changes in overflow rate within the narrow range experienced (300 - 600 gpd/ft^2 or 14.7 - 29.3 cu m/sq m/day). Corresponding results from settling columns within this general range support this. Settling column data indicate that there was gradual deterioration of effluent quality with the increase in overflow rate and only 30 to 35 percent removal was obtained when overflow rate was increased to 2000 gpd/ft^2 (99 cu m/sq m/day), whereas the results obtained from the Ontario Ministry of the Environment show complete washout at this overflow rate in plant. It should be noted, however, that detention time was also proportionately reduced with the increase in overflow rate.

Figure 18 shows the effect of overflow rate when detention time was kept constant. In this case an overflow rate of as high as 2000 gpd/sq ft (99 cu m/sq m/day) did not drastically effect effluent quality.

From Figure 19 it can be seen that major settling occurred (particularly when chemical was added) during the first 20 minutes or so (equivalent to 40 minutes in actual clarifier). This will be investigated further by in-plant studies. It is also clear that chemical addition caused a decrease of suspended solids in effluent by about 50 mg/l (29% more than obtained with no chemical addition). Furthermore, the net reduction in suspended solids is not affected by

detention time after 20 minutes as indicated by the parallel and almost horizontal lines in Figure 19.

<u>Field Studies at Windsor</u>

Figure 20 indicates that at Windsor most of the settleable solids settled during the first 10 minutes (probably 20 minutes in plant clarifier). Chemical addition improved settling rate, particularly addition of polymer was very effective. Average suspended solids in grab samples of effluent at the time of experiments was about 11 mg/l with plant detention time of 180 minutes. About the same quality of effluent was estimated to be achieved from settling column with detention time of about 90 minutes. This fact also supports the conclusion derived from results of Sarnia plant i.e. to produce the same quality of effluent at a given overflow rate, plant clarifier will require about twice the detention time as determined by the settling column test.

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APPENDIX A

PROCEDURES FOR CHEMICAL ADDITION IN

LABORATORY AND PILOT-SCALE EXPERIMENTS

A-1 CHEMICAL ADDITION IN LABORATORY

(a) Without Polymer Use

1. Pour 40 litres of sample into a container.
2. Start mixing rapidly with an electric mixer.
3. Add slowly the desired quantity of coagulant (as determined by jar test).
4. Mix rapidly for 1-1/2 to 2 minutes.
5. Pour the mixture in settling column.
6. Flocculate the mixture by recycling through the pump for 20 minutes. Recycling rate used in the experiment was about 15 litres (3.33 Imp. Gal.) per minute. This was just enough to keep the suspended solids in suspension.
7. Stop the pump and start taking samples (25 ml.) from all the ports.
8. To take samples, push in the port tube, flush it by wasting about 15 - 20 ml. mixture, and take the sample from the centre of the column. After taking the sample pull out the tube just enough that it does not obstruct settling of particles.
9. As water level in the column will change after the withdrawal of samples, take depths from sampling ports to water level before taking samples each time.
10. Determine suspended solids in the mixture withdrawn from the ports by filtering it through 0.45 micron membrane filter paper.
11. Record temperature of the mixture before and after the experiment.
12. Record all information in a tabular form (see Form 1).
13. Take samples for phosphate and other determinations at the end of each run.

FORM 1

Port No.	Time Mins.	Depth	Sample Vol.mi.	Dish No.	Wt. of Dish	Wt. of SS + Dish	Wt. of S.S.	Conc. mg/l.	

Form 2

SETTLING COLUMN

A. Treatment Plant .... Nature of sample ....

Date .... Time ....

B. Chemical (Coagulant) used ....

Mixing time .... minutes flocculation time .... minutes

C. Initial Determinations:

pH .... Alkalinity ....

Phosphates:

a) Un-filtered . . . Poly-................ppm
Ortho-...............ppm

b) Filtered . . . . Poly-................ppm
Ortho-...............ppm

D. Determinations at the end of test run:

pH.......... Alkalinity............

Phosphates:

a) Un-filtered . . . Poly-................ppm
Ortho-...............ppm

b) Filtered . . . . Poly-................ppm
Ortho-...............ppm

Remarks:

(b) With Polymer Use

1. Pour 10 litres of sample into short column (2'0" long).

2. Start mixing rapidly with an electric mixer.

3. Add slowly the desired quantity of coagulant.

4. Mix rapidly for 1-1/2 to 2 minutes.

5. Flocculate for one minute at slow speed.

6.1 Increase mixer speed and slowly add the desired quantity of polymer (use 0.05% solution, and dilute it in 10 ml. of distilled water).

6.2 Mix rapidly for 1/2 minute.

6.3 Reduce mixer speed and allow the mixture to flocculate for three minutes.

7. Stop the mixer and remove it.

8. To take samples, push in the port tube, flush it by wasting about 15 - 20 ml. mixture, and take the sample from the centre of the column. After taking the sample pull out the tube just enough that it does not obstruct settling of particles.

9. As water level in the column will change after the withdrawal of samples, take depths from sampling ports to water level before taking samples each time.

10. Determine suspended solids in the mixture withdrawn from the ports by filtering it through 0.45 micron membrane filter paper.

11. Record temperature of the mixture before and after the experiment.

12. Record all information in a tabular form (see Form 1).

13. Take samples for phosphate and other determinations at the end of each run. (see Form 2)

A-11 CHEMICAL ADDITION IN PLANT

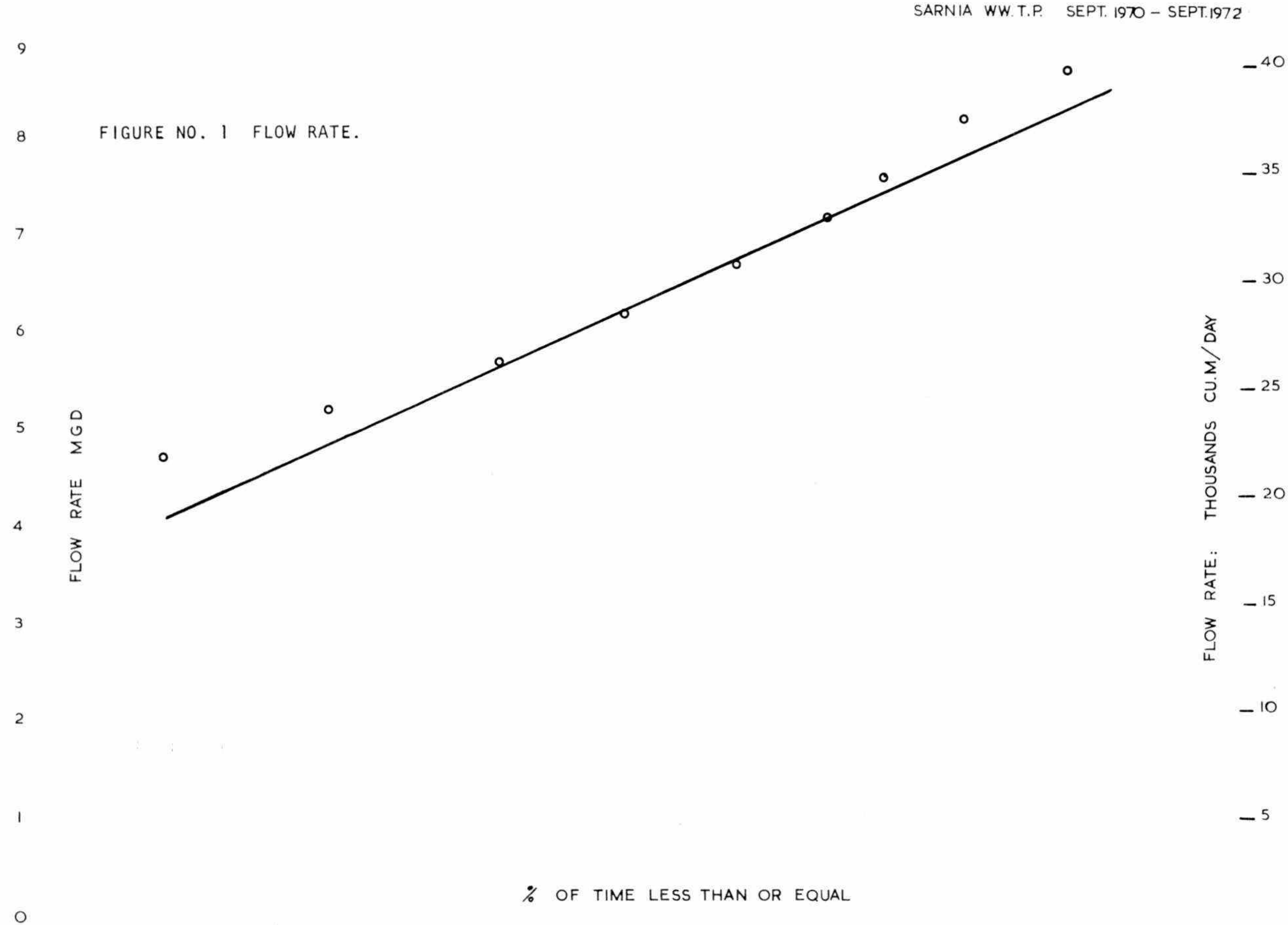
At the Sarnia plant inorganic chemical was added in the preaeration tank where mixing took place by diffused air for about 15 - 20 minutes depending on the flow rate. When polymer was also used, it was added at the end of the preaeration tank. The mixture was subsequently agitated for a fraction of a minute only before it discharged into the clarifiers.

At Windsor, the addition point was at the suction side of the raw sewage pump where it was vigorously mixed momentarily in the pump. The level of turbulence gradually decreased as the wastewater travelled to clarifiers. The travel time from the point of addition of chemical to the clarifier inlet was estemated to average about three minutes. When polymer was also used, it was added at the inlet of distribution chamber.

Samples of raw wastewater were taken from the preaeration tank and wet well at Sarnia and Windsor plants respectively. Samples with chemical addition were taken from the inlet of clarifier. The samples were carried in 40 litres volume to the laboratory and poured into the settling column by bucket;uniformly mixed by recycling through the pump for three minutes at a rate of about 15 litres (3.3 Imp. gal.) per minute. The rest of the experiment was carried out in the same manner as described in Section A-1, steps 8 to 12.

APPENDIX B

PICTORIAL PRESENTATION OF RESULTS


SARNIA WW. T.P. SEPT. 1970 – SEPT. 1972
FIGURE NO. 1 FLOW RATE.
FLOW RATE MGD
9
8
7
6
5
4
3
2
1
0
FLOW RATE: THOUSANDS CU.M./DAY
40
35
30
25
20
15
10
5
% OF TIME LESS THAN OR EQUAL

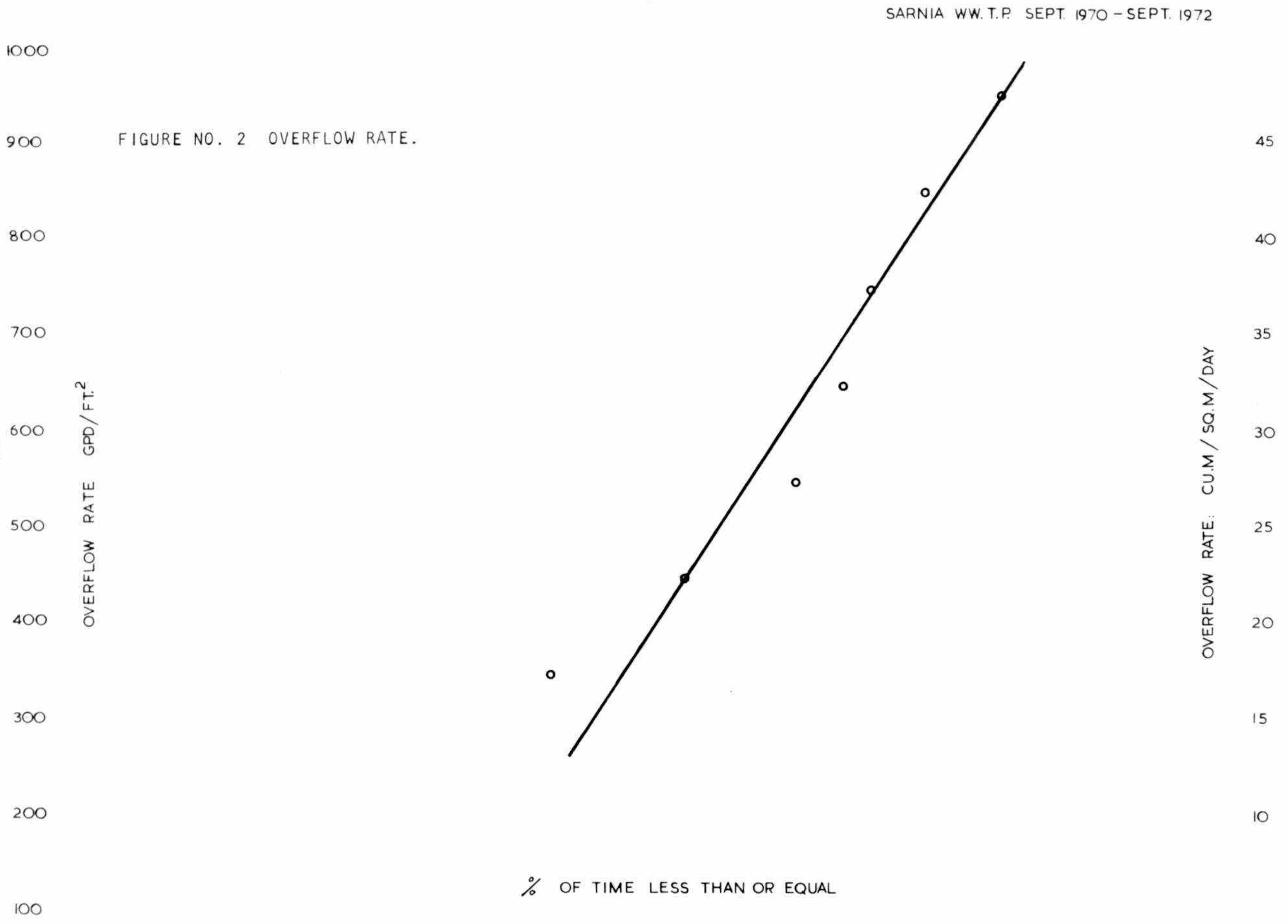


FIGURE NO. 2 OVERFLOW RATE.

SARNIA WW. T.P SEPT. 1970 – SEPT. 1971

FIGURE NO. 3

SUSPENDED SOLIDS - NO CHEMICAL ADDITION.

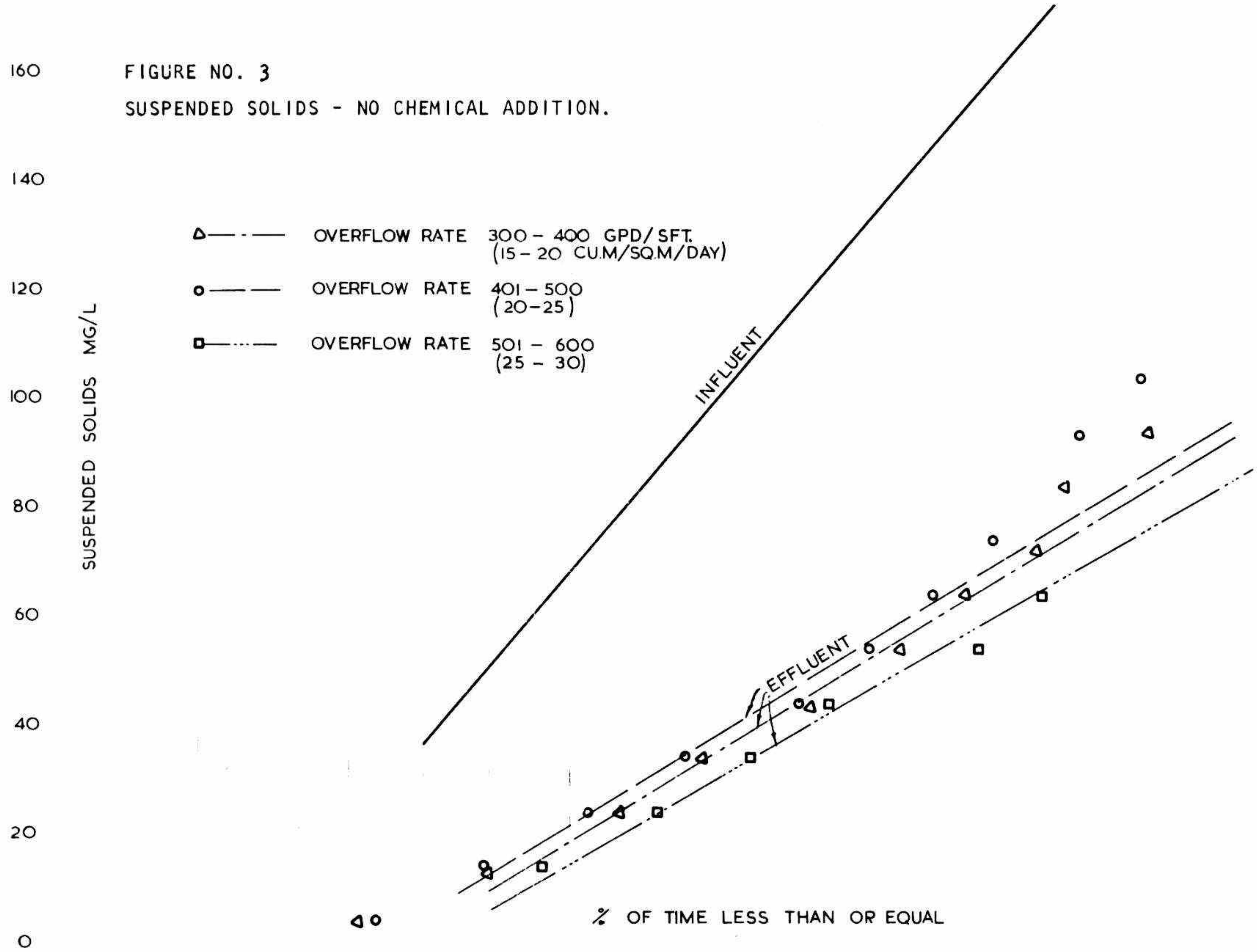
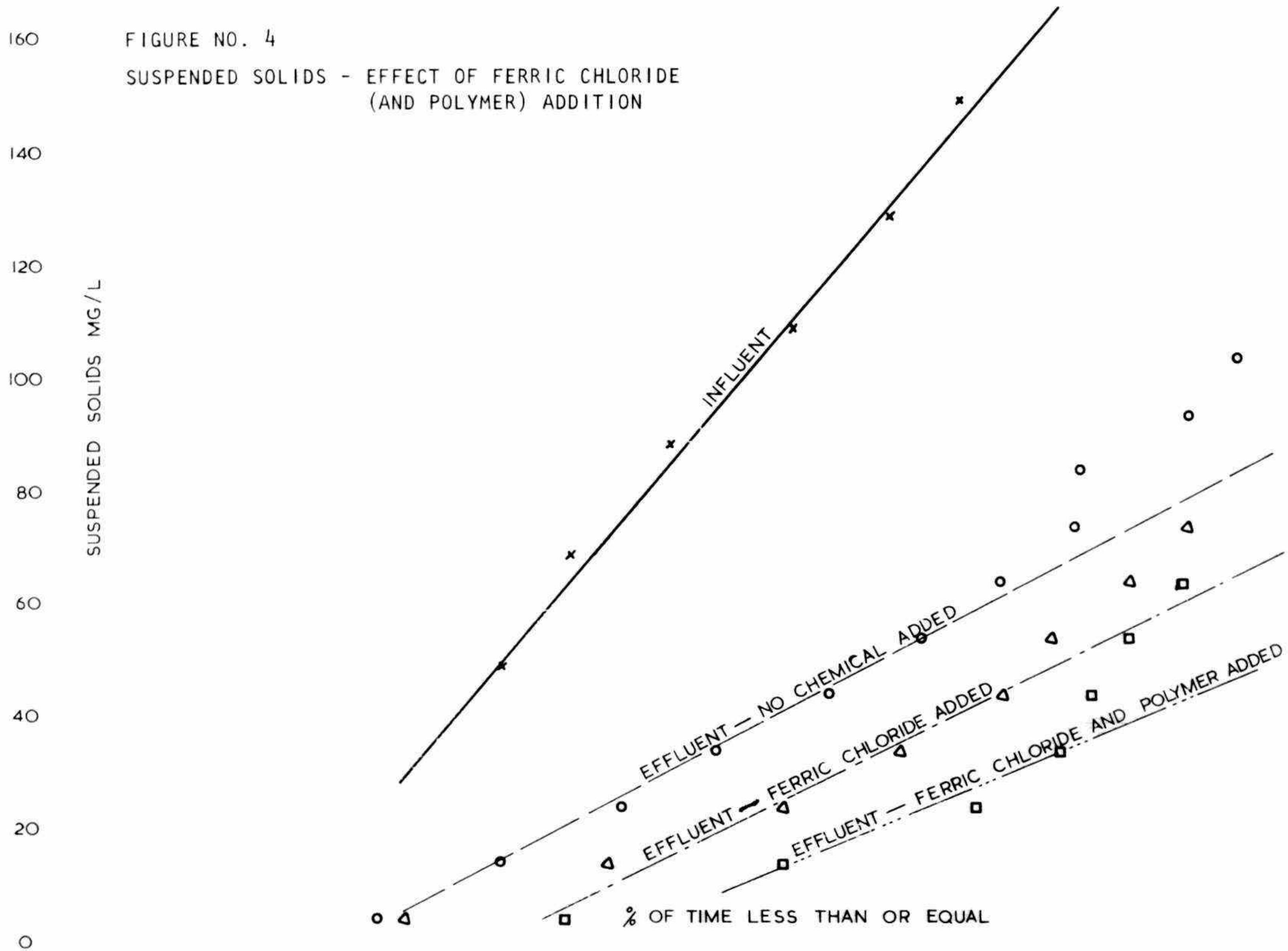


FIGURE NO. 4

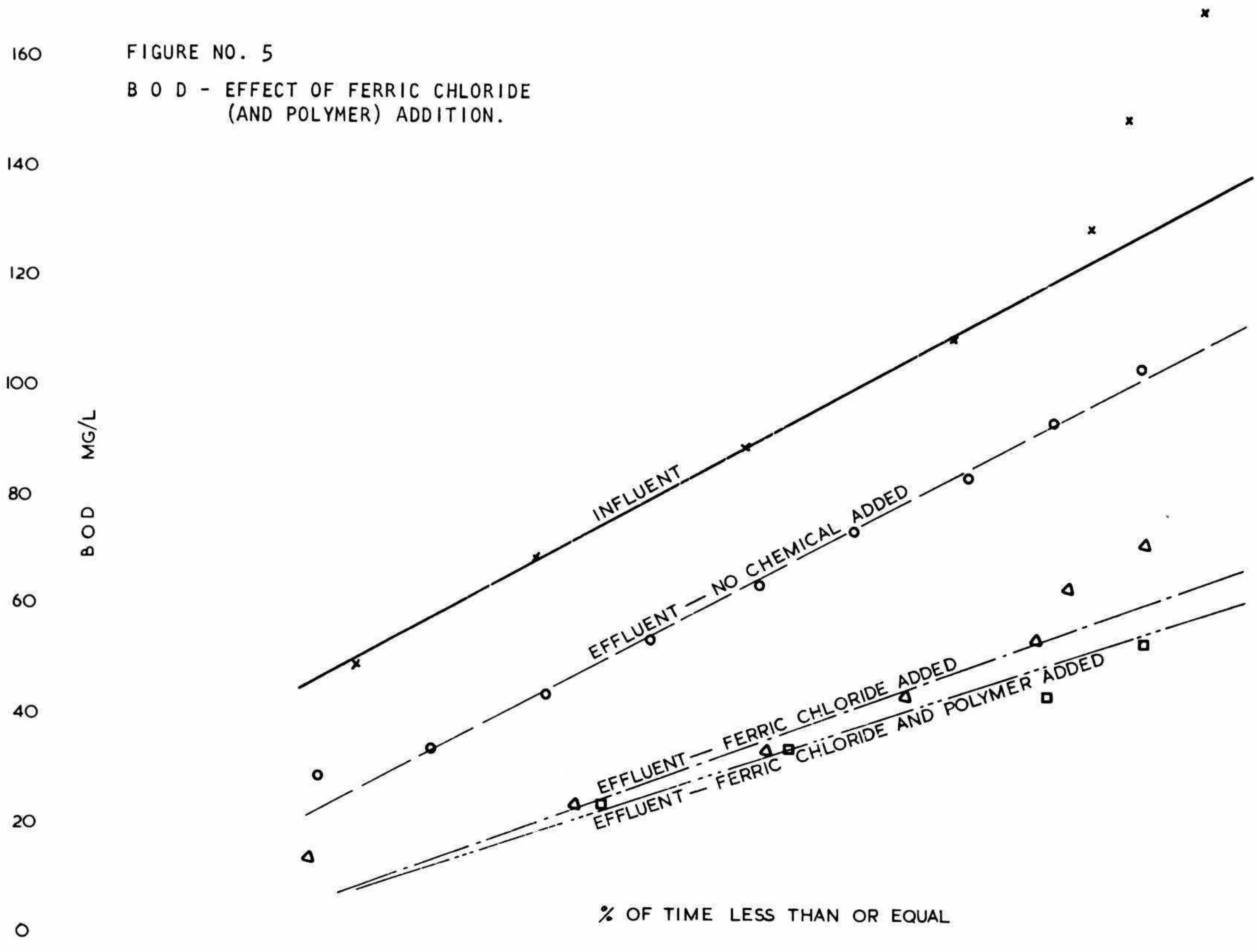
SUSPENDED SOLIDS - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION



SARNIA WW. T.P SEPT. 1971 - JULY 1972.

FIGURE NO. 5

B O D - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION.



SARNIA WW.T.P. SEPT. 1971 – JULY 1972.

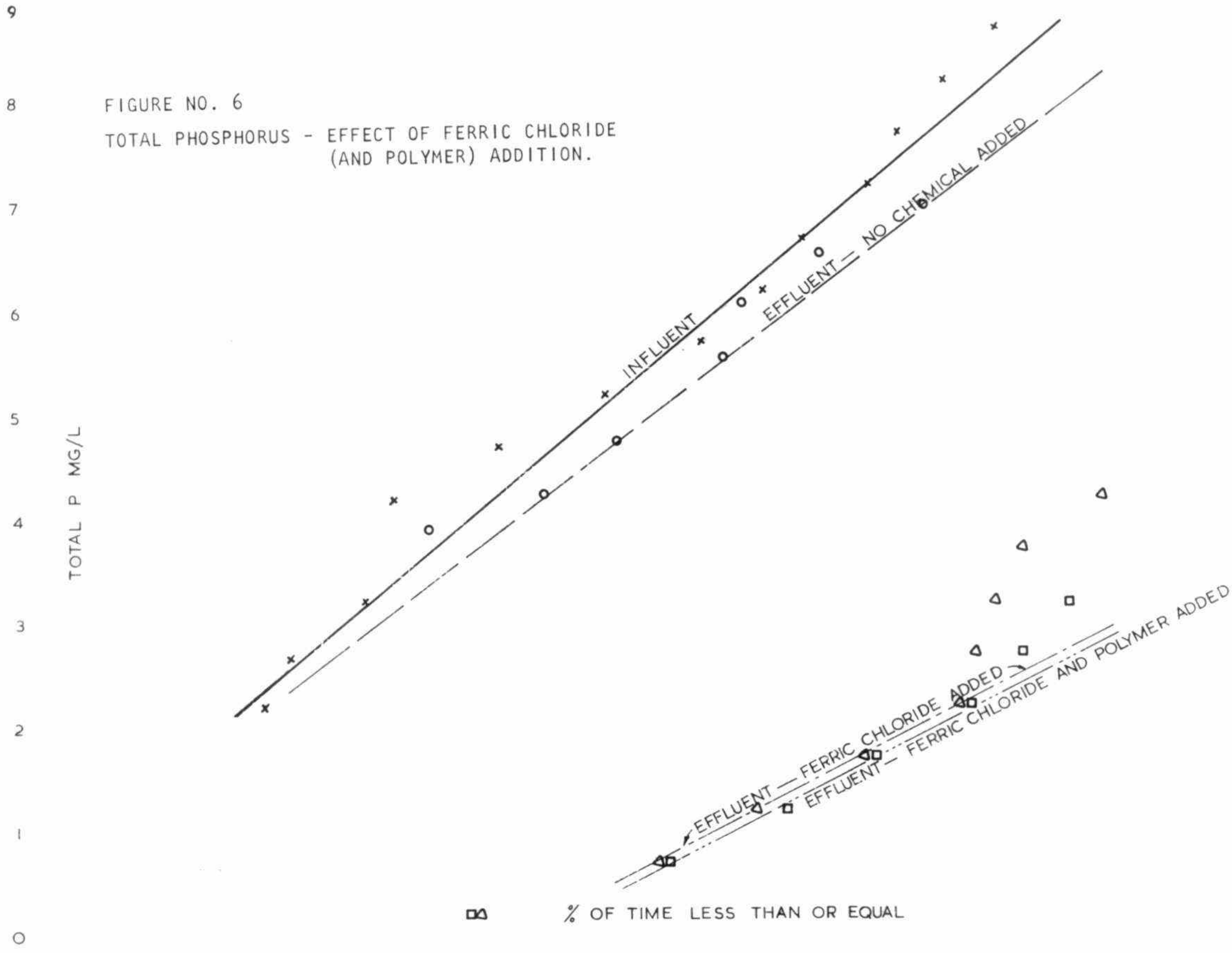


FIGURE NO. 6
TOTAL PHOSPHORUS - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION.

FIGURE NO. 7

SUSPENDED SOLIDS - EFFECT OF ALUM (AND POLYMER) ADDITION.

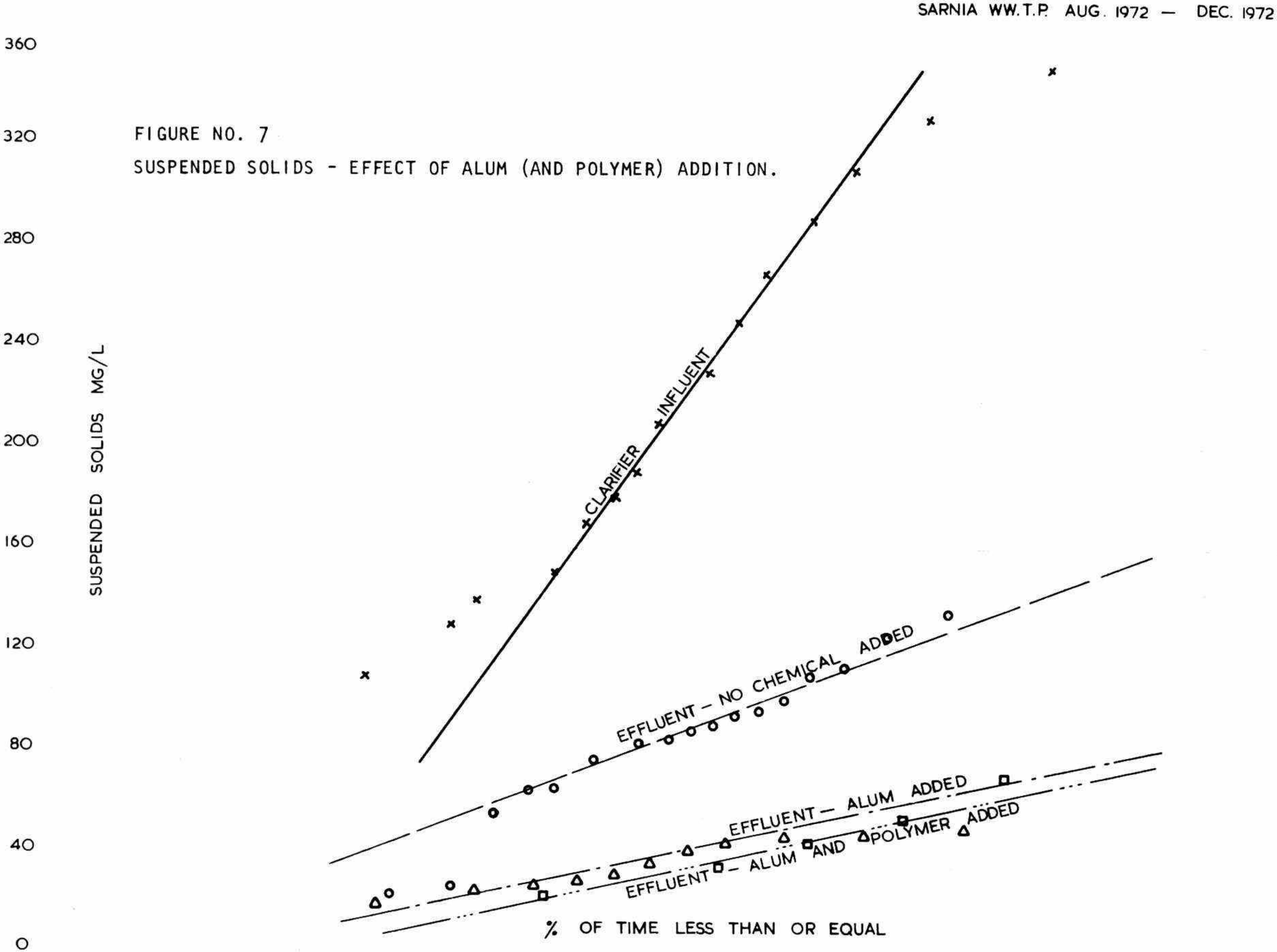
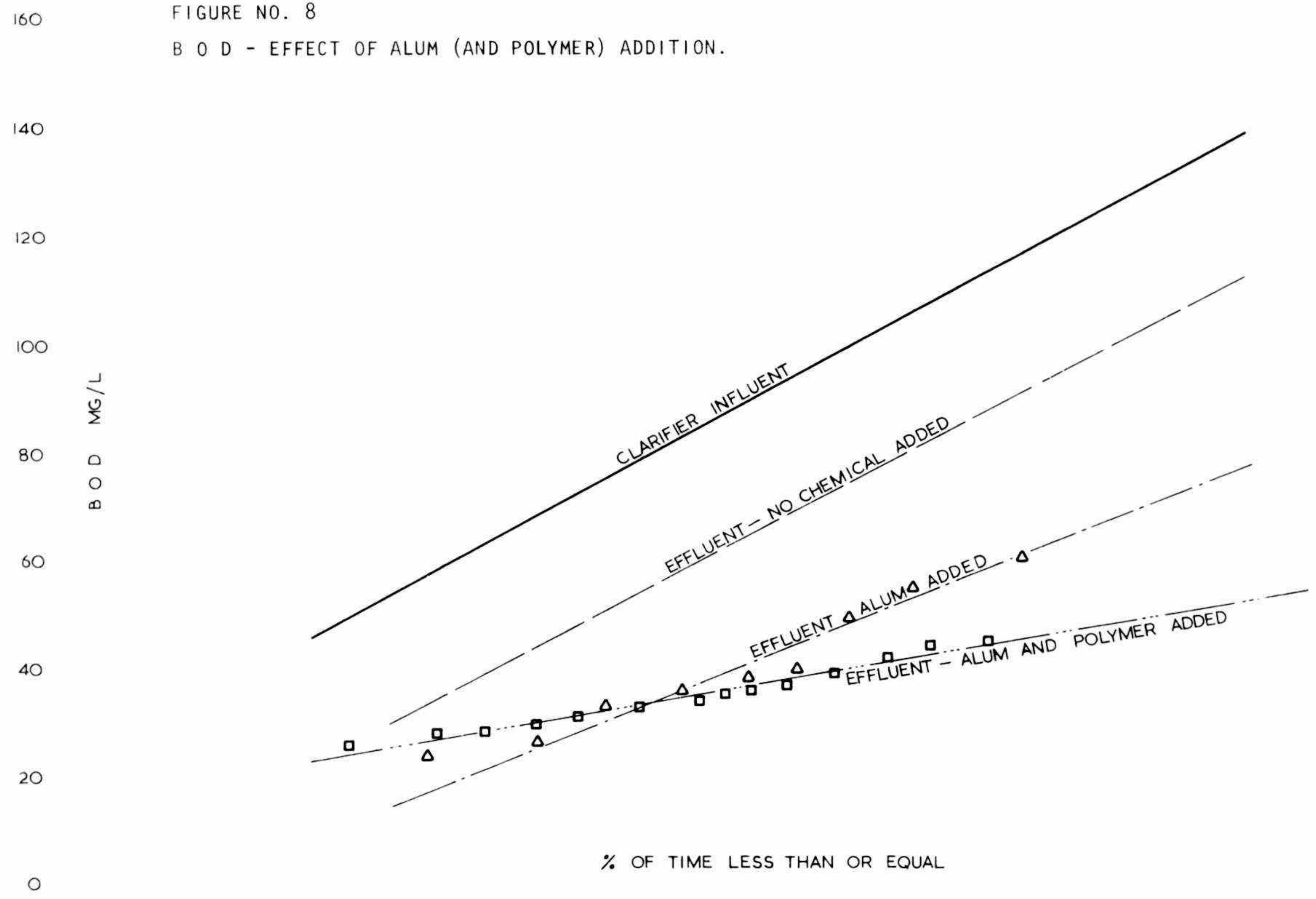


FIGURE NO. 8

B O D - EFFECT OF ALUM (AND POLYMER) ADDITION.



SARNIA WW.T.P. AUG. 1972 — DEC. 1972

FIGURE NO. 9

TOTAL PHOSPHORUS - EFFECT OF ALUM (AND POLYMER) ADDITION.

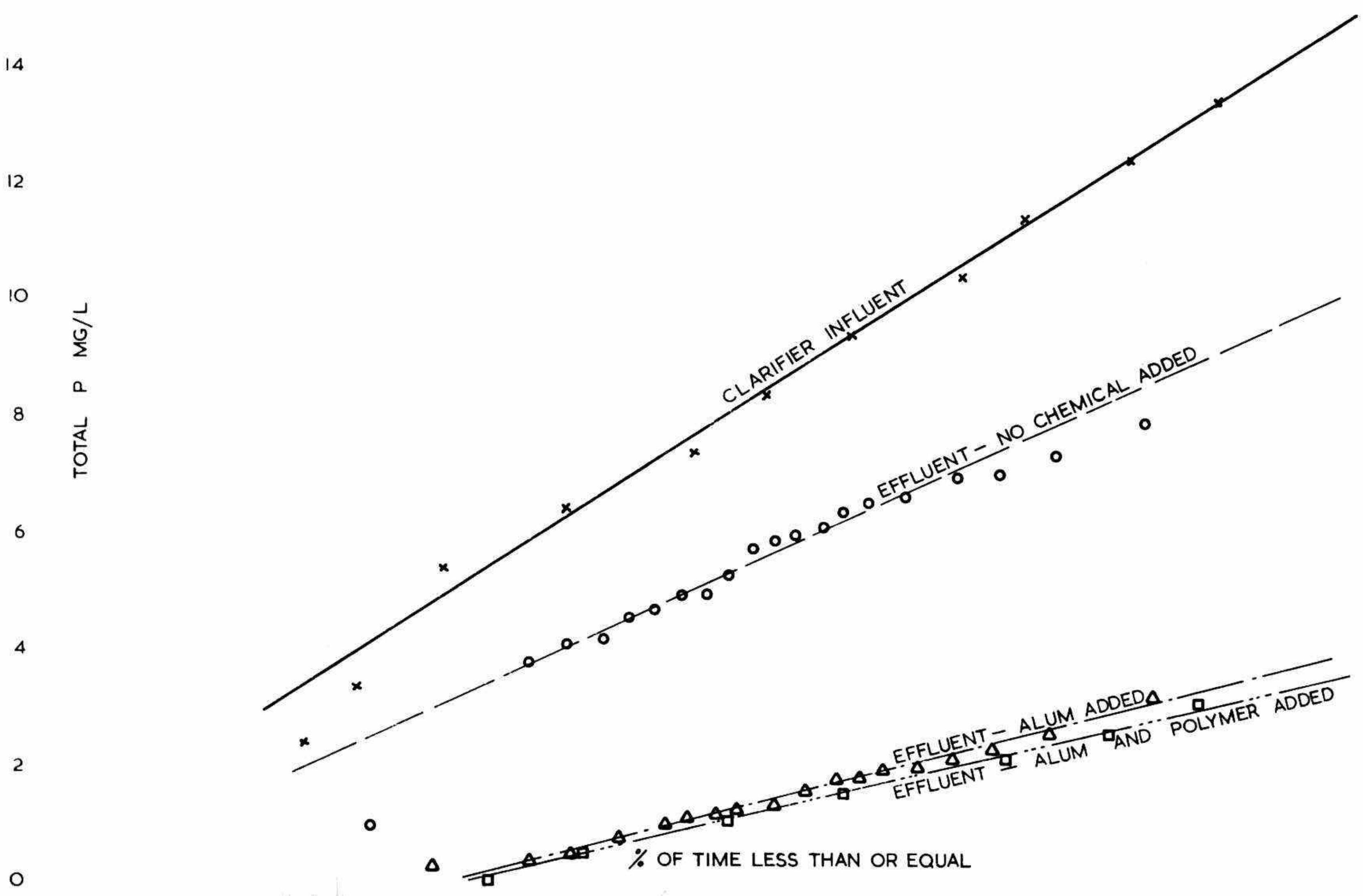
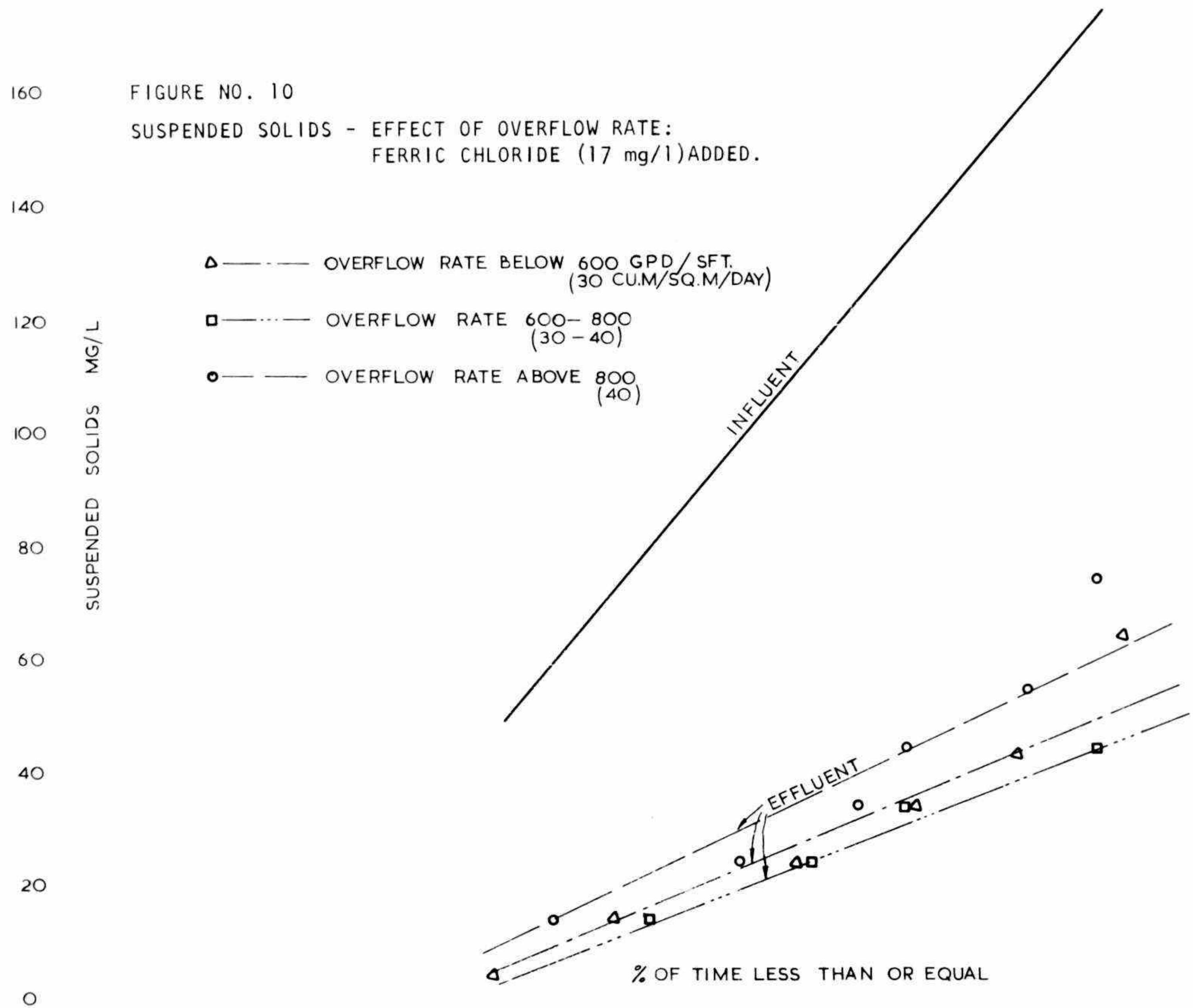


FIGURE NO. 10

SUSPENDED SOLIDS - EFFECT OF OVERFLOW RATE:
FERRIC CHLORIDE (17 mg/l) ADDED.



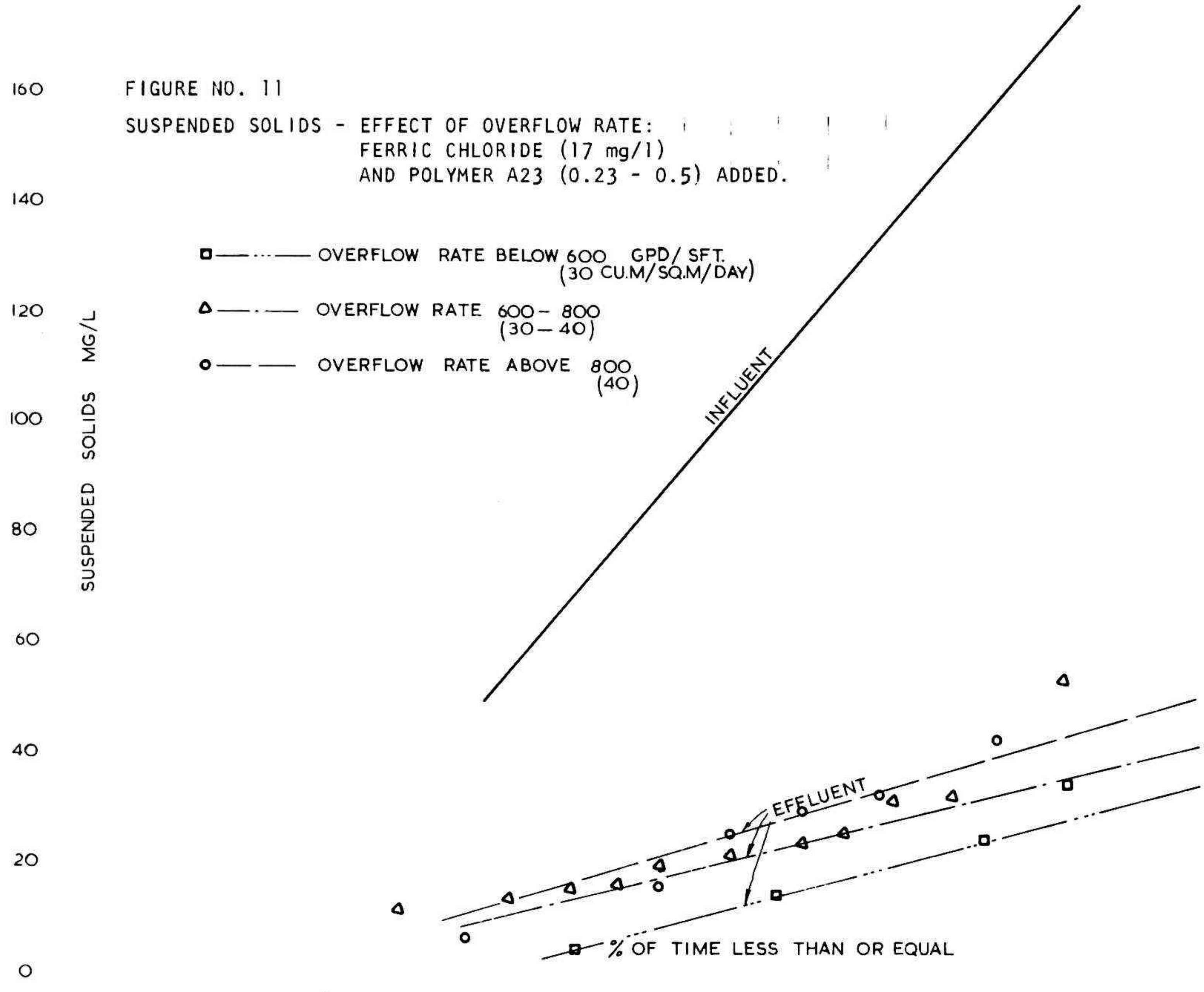


FIGURE NO. 11

SUSPENDED SOLIDS - EFFECT OF OVERFLOW RATE:
FERRIC CHLORIDE (17 mg/l)
AND POLYMER A23 (0.23 - 0.5) ADDED.

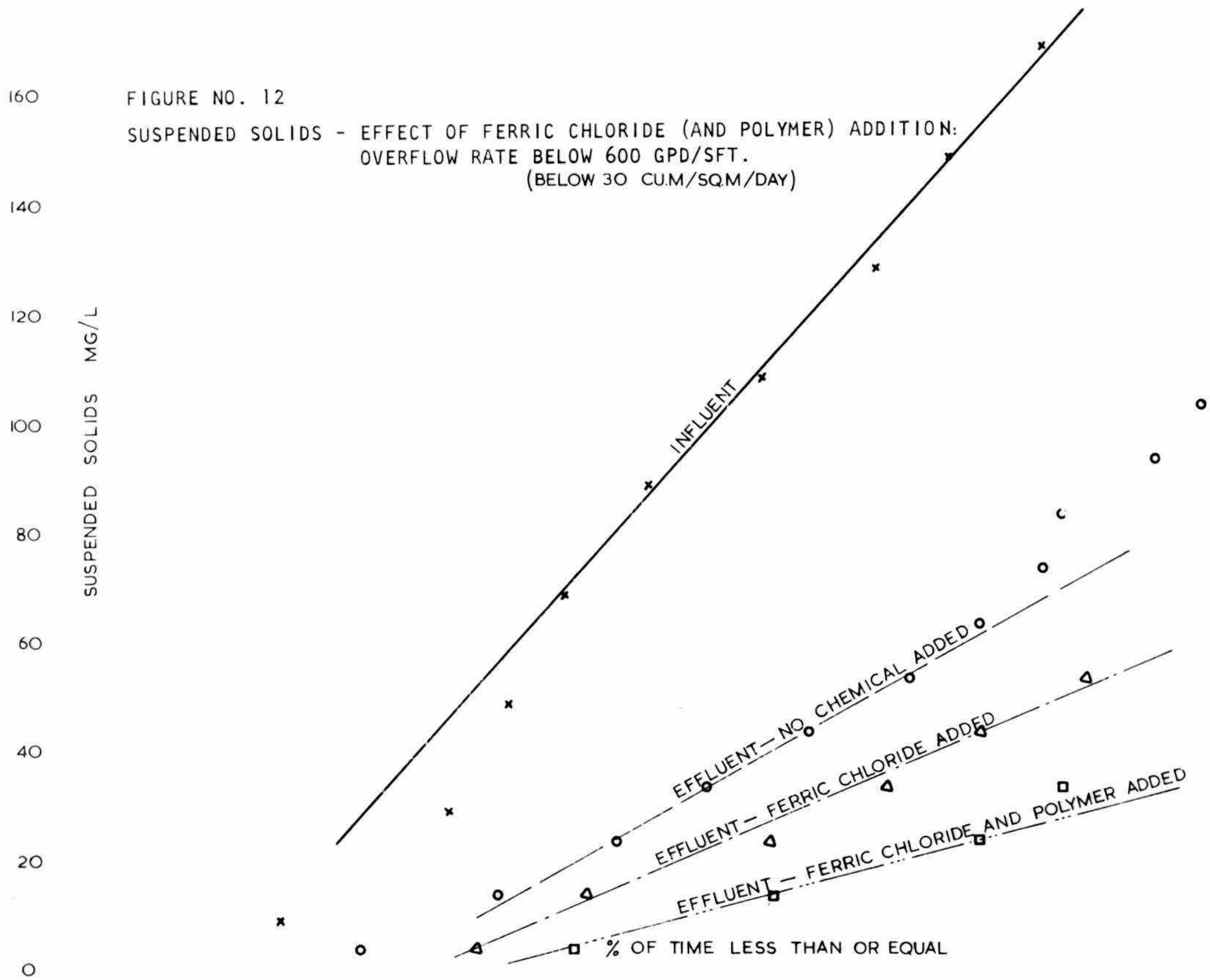


FIGURE NO. 12

SUSPENDED SOLIDS - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION:
OVERFLOW RATE BELOW 600 GPD/SFT.
(BELOW 30 CU.M/SQ.M/DAY)

SARNIA WW.T.P. SEPT. 1971 — JULY 1972

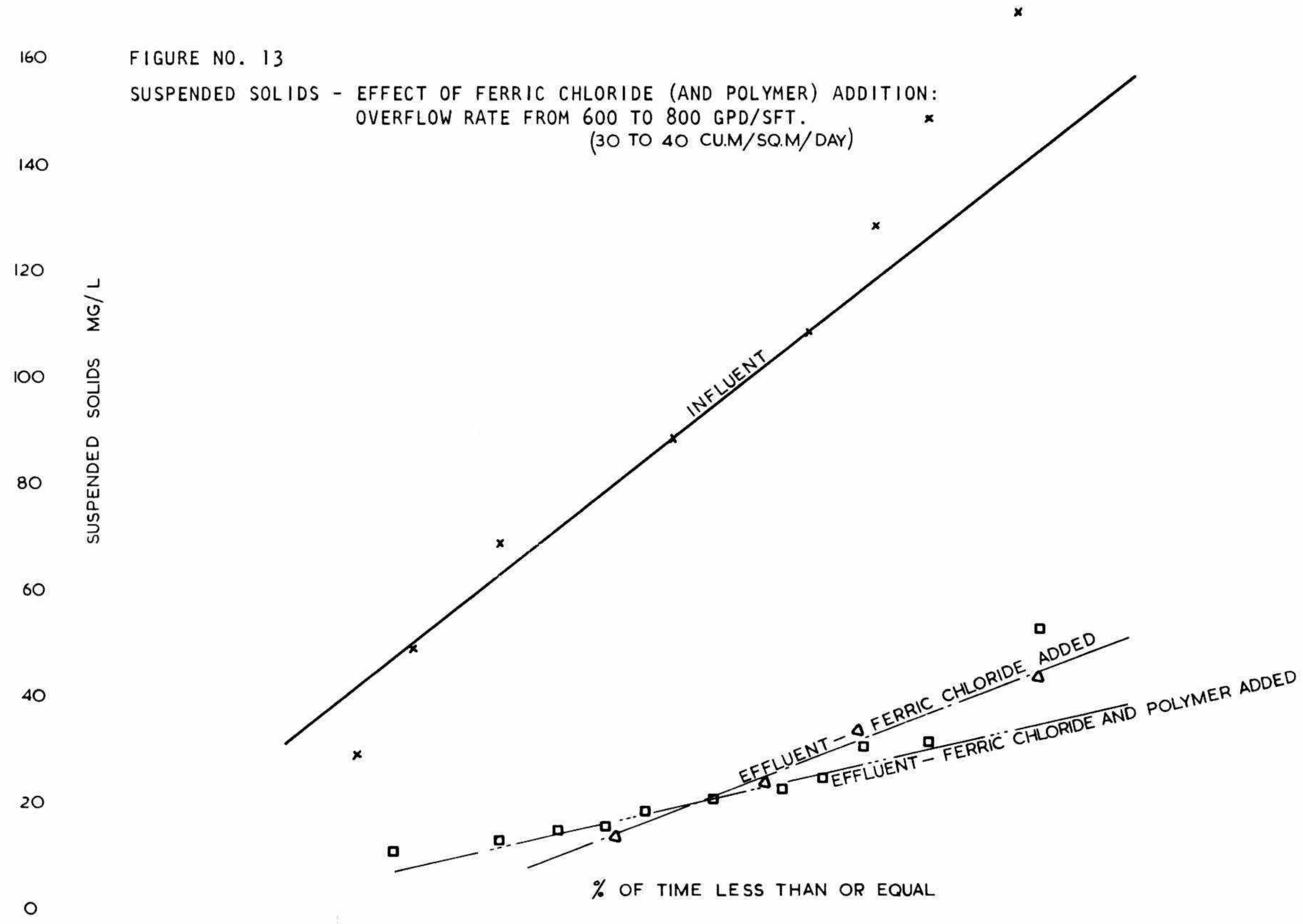
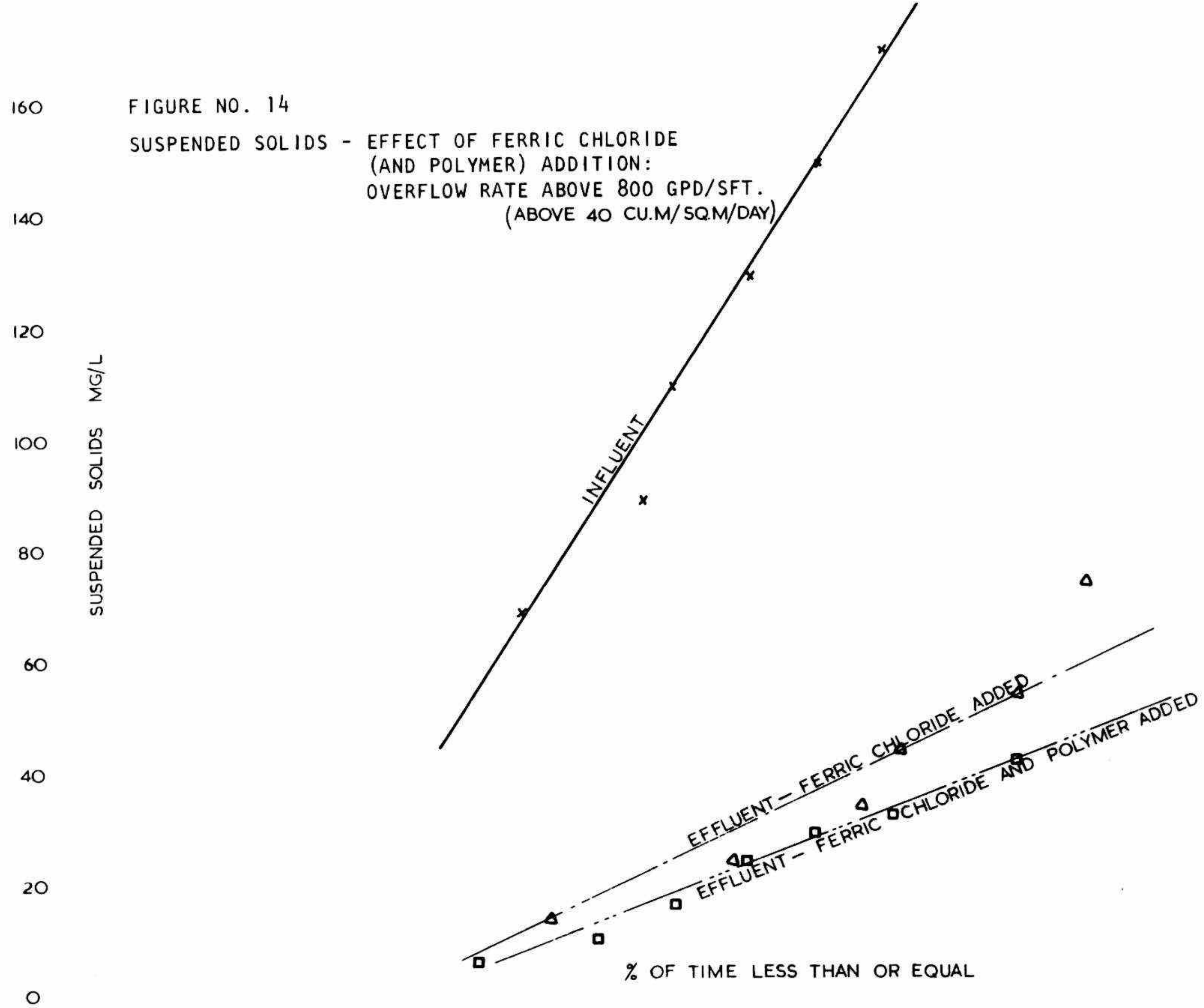


FIGURE NO. 13

SUSPENDED SOLIDS - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION:
OVERFLOW RATE FROM 600 TO 800 GPD/SFT.
(30 TO 40 CU.M/SQ.M/DAY)

FIGURE NO. 14

SUSPENDED SOLIDS - EFFECT OF FERRIC CHLORIDE (AND POLYMER) ADDITION: OVERFLOW RATE ABOVE 800 GPD/SFT. (ABOVE 40 CU.M/SQ.M/DAY)



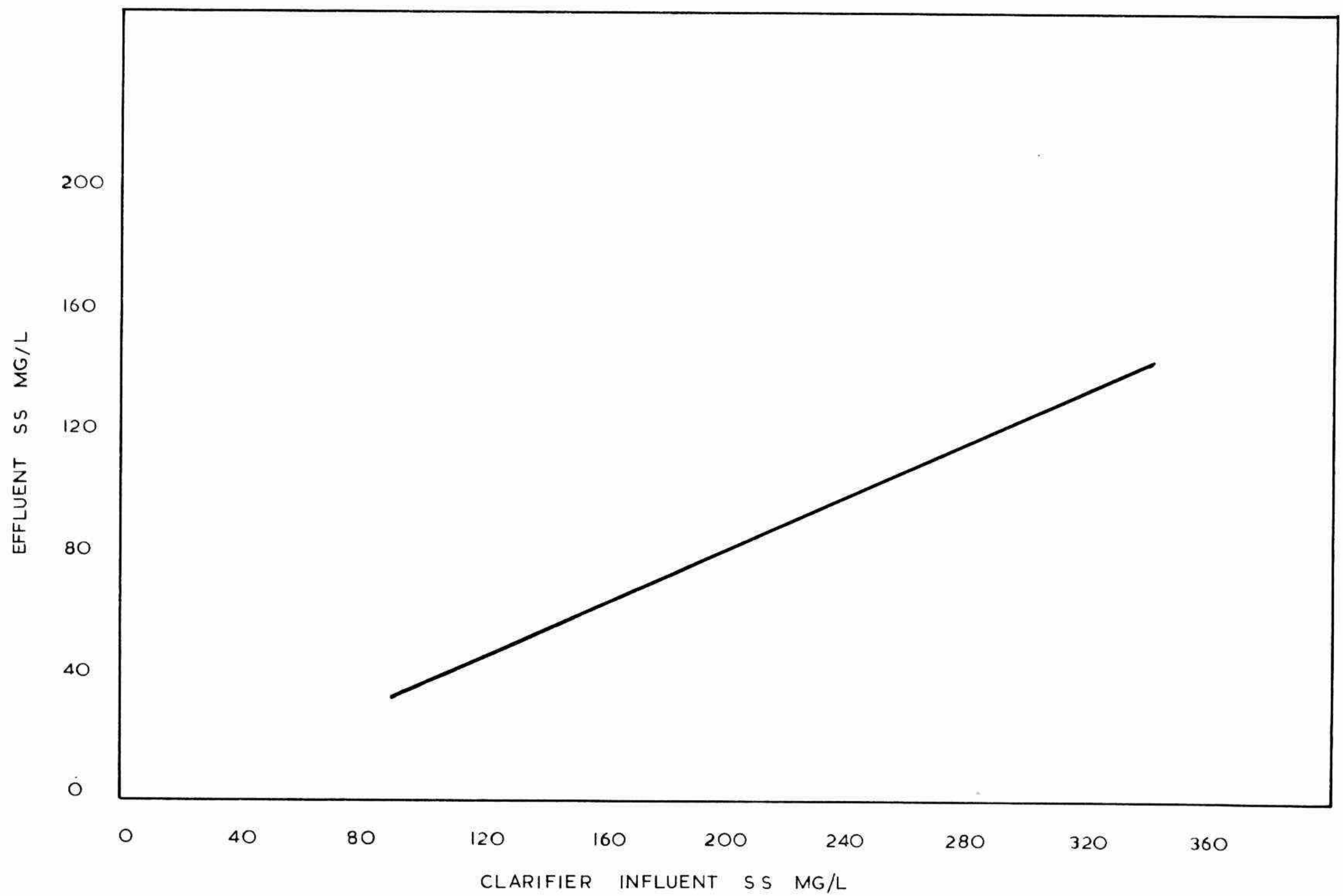


FIGURE NO. 15 CORRELATION OF INFLUENT AND EFFLUENT SUSPENDED SOLIDS - WITHOUT CHEMICAL ADDITION. (FROM FIG.

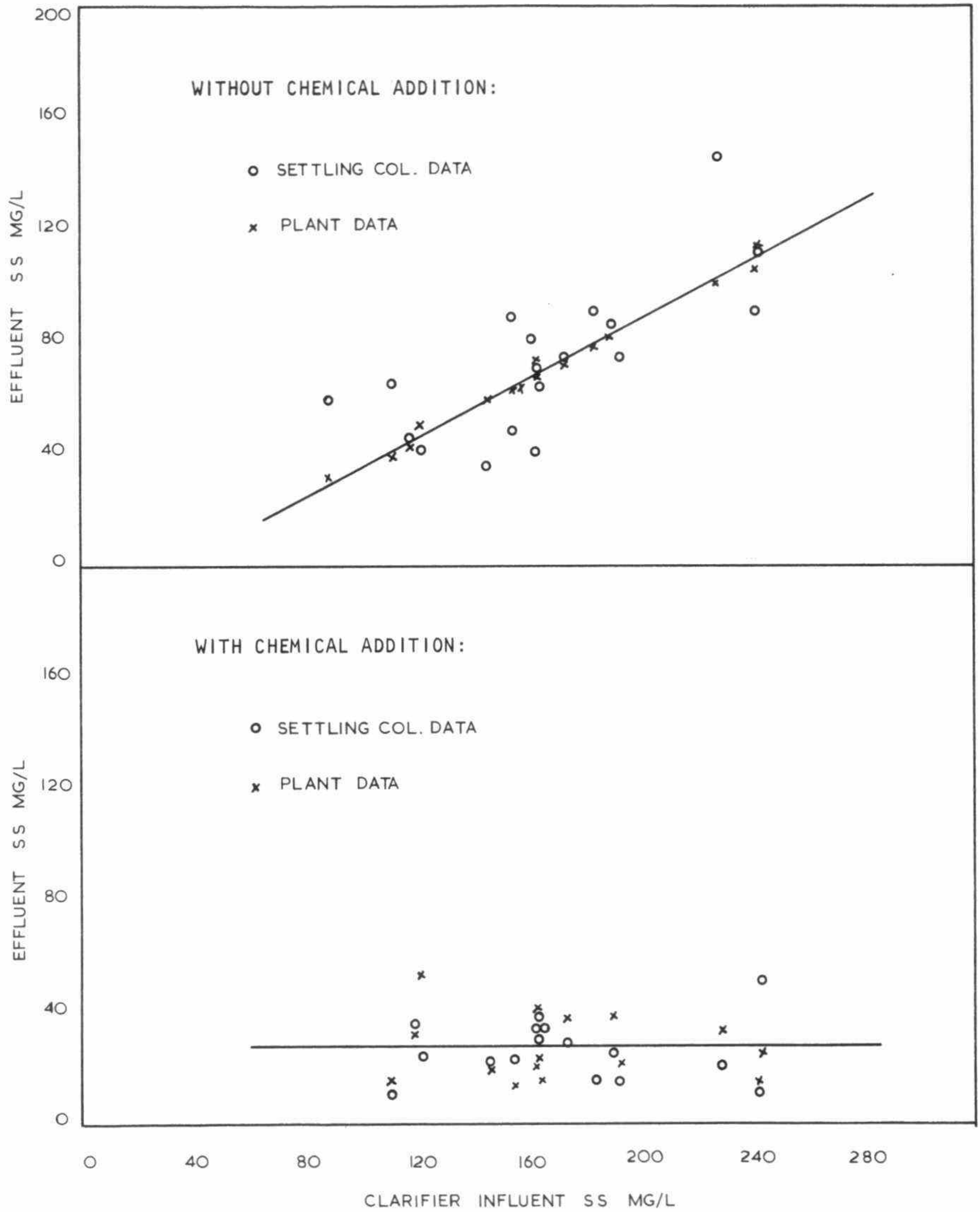


FIGURE NO. 16 COMPARISON OF SETTLING COLUMN AND PLANT PERFORMANCE.

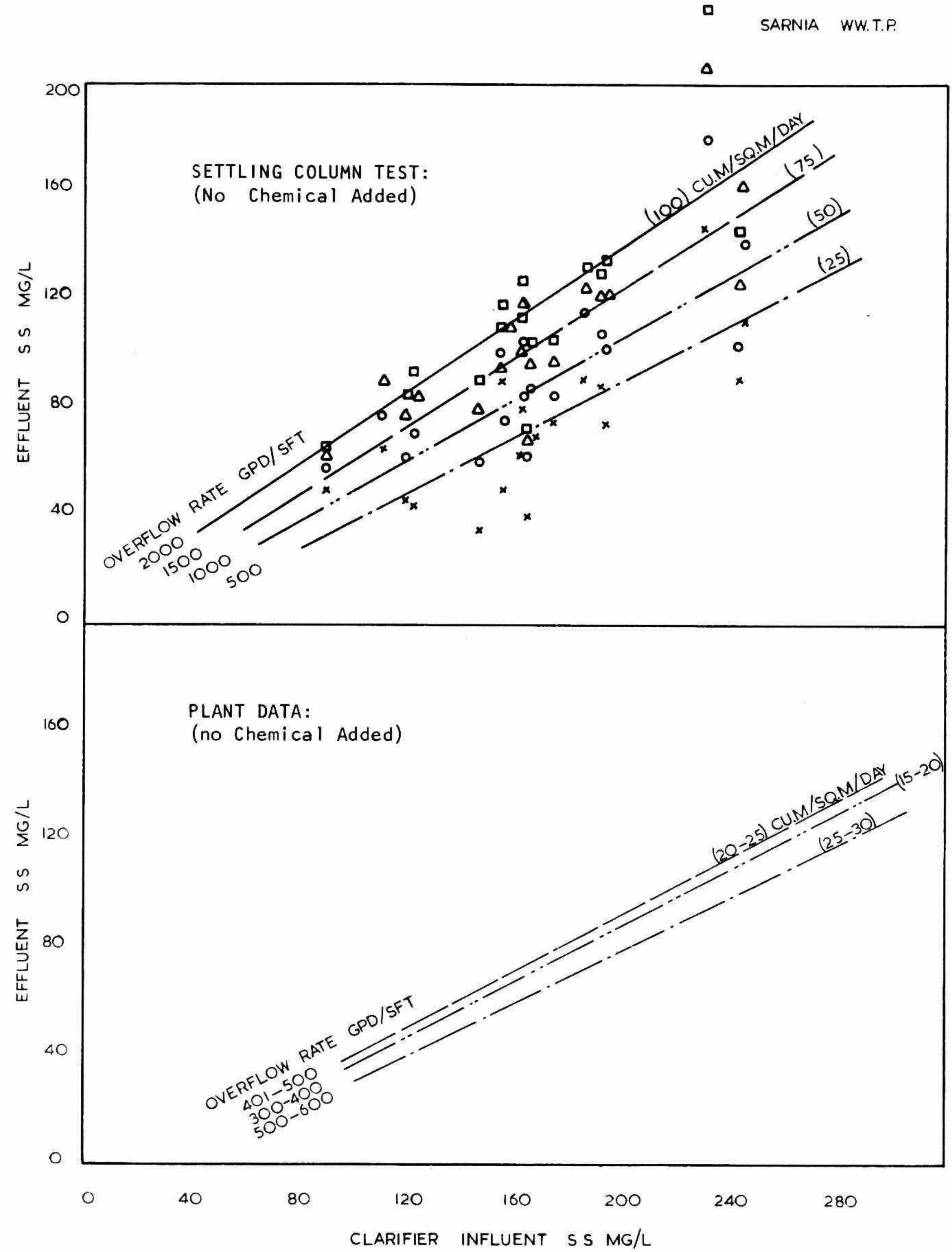


FIGURE NO. 17 EFFECT OF OVERFLOW RATE (DET. TIME INV. PROPORTIONAL TO OVERFLOW RATE).

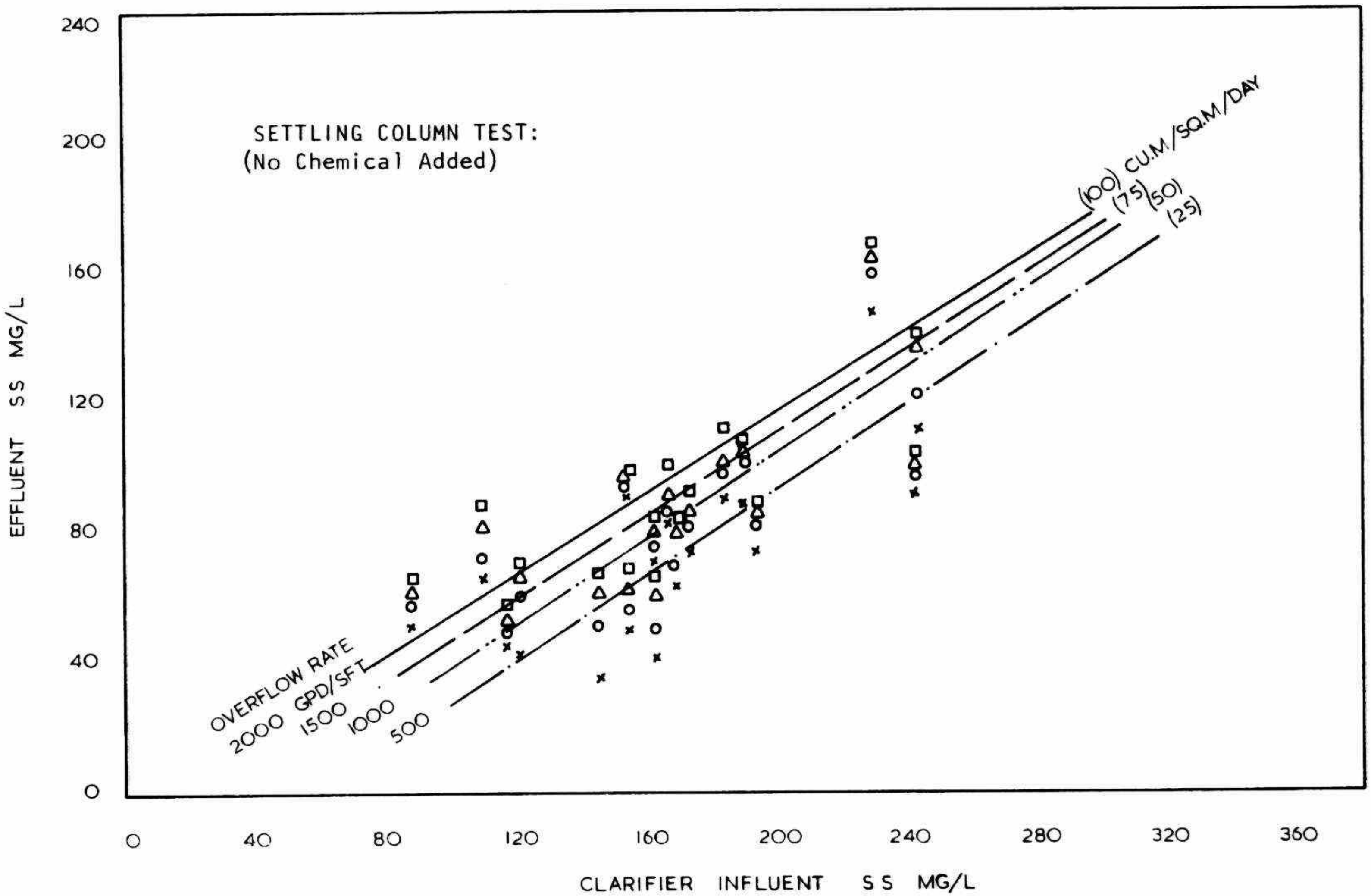


FIGURE NO. 18 EFFECT OF OVERFLOW RATE (DETENTION TIME CONSTANT)

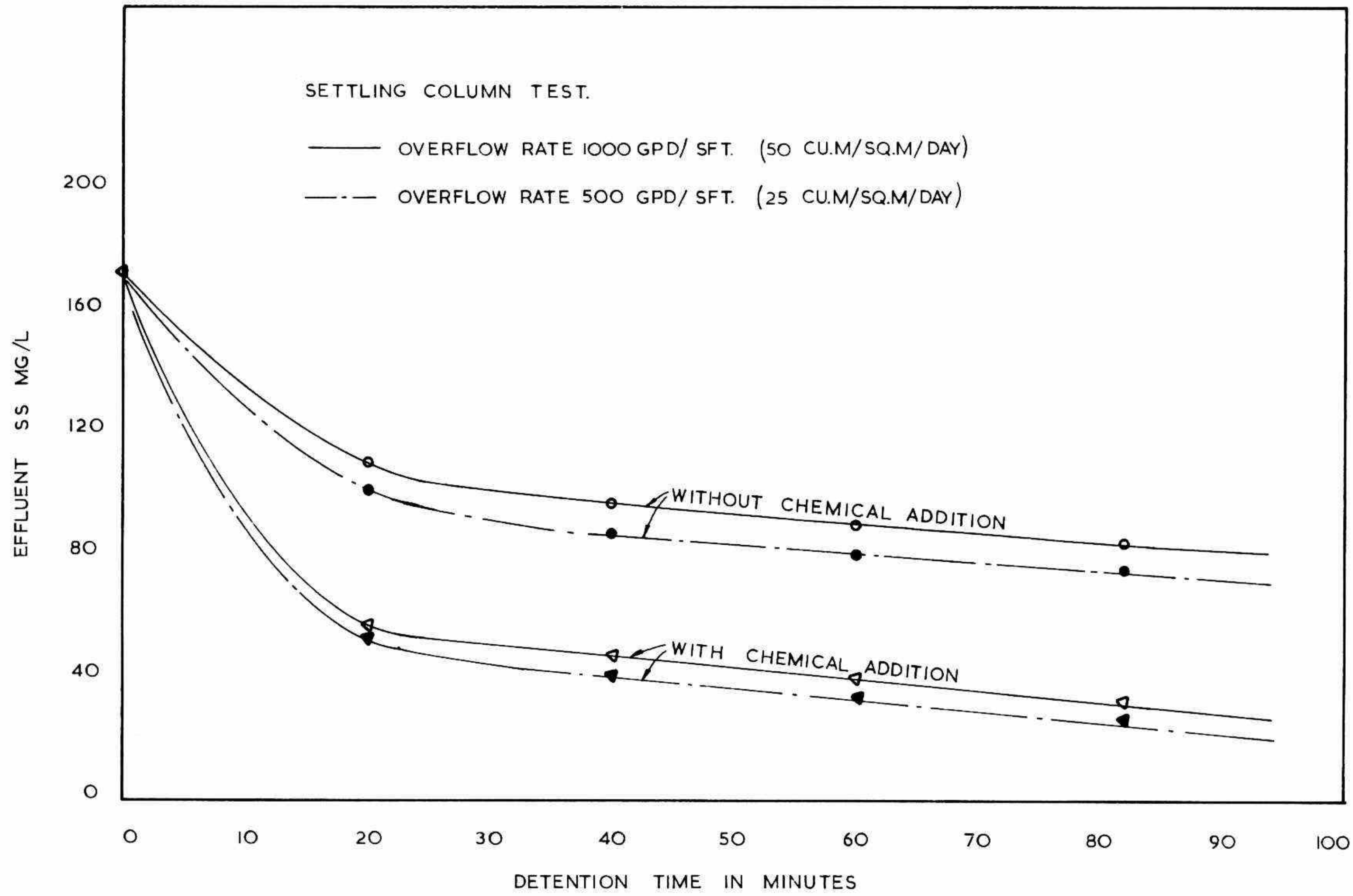


FIGURE NO. 19 EFFECT OF DETENTION TIME ON CLARIFICATION - WITH AND WITHOUT CHEMICAL ADDITION.

WINDSOR WW.T.P.

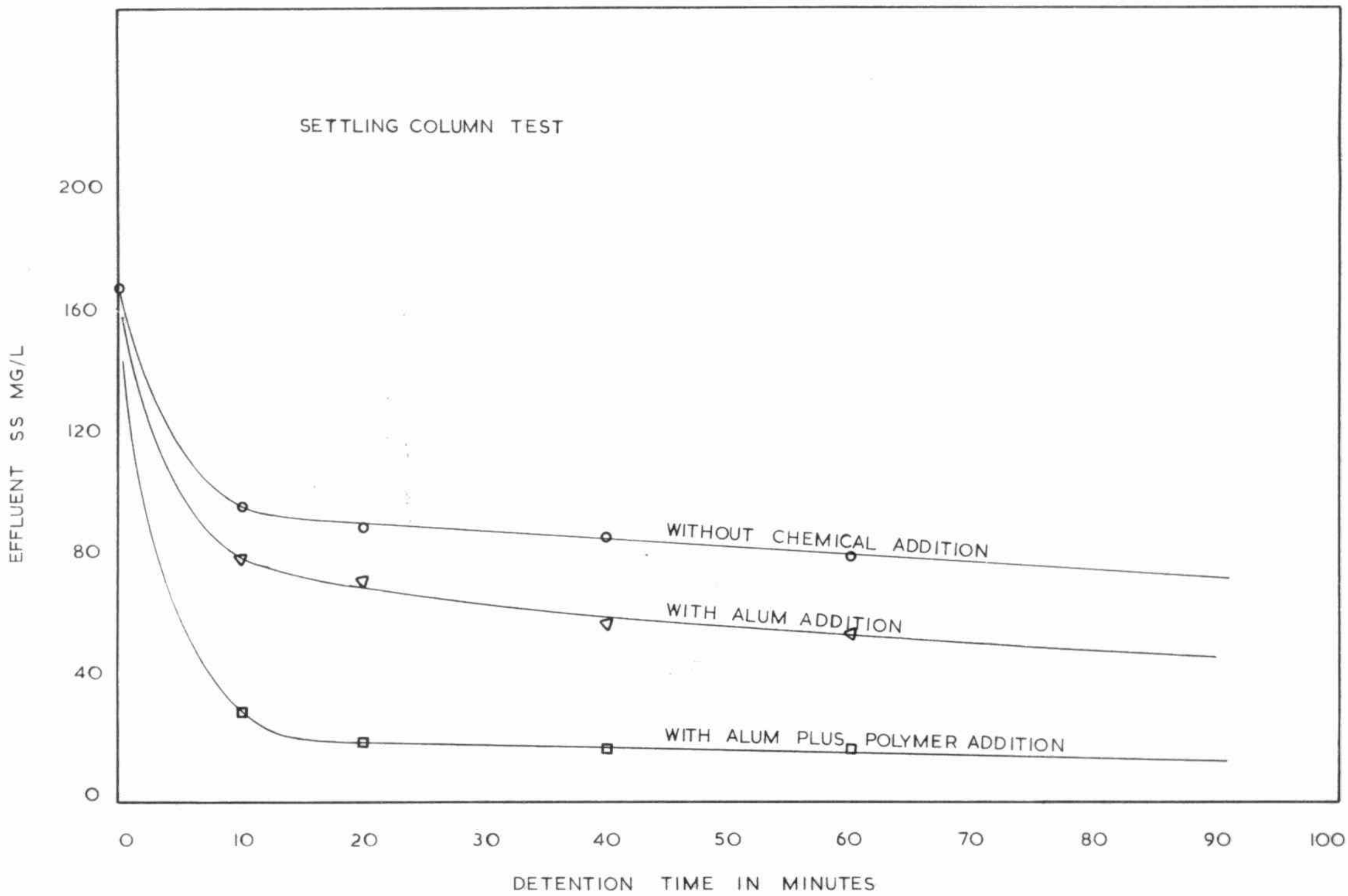


FIGURE NO. 20 EFFECT OF DETENTION TIME ON CLARIFICATION (at Windsor)